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Volatile Organic Compound Control at Specific Sources in Louisville, Kentucky, and Nashville, Tennessee

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Durham, NC

Prepared for

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VOLATILE ORGANIC COMPOUND CONTROL AT SPECIFIC SOURCES IN LOUISVILLE, KY, AND NASHVILLE, TN

FINAL

Prepared for:

U.S. ENVIRONMENTAL PROTECTION AGENCY
Region 4
345 Courtland Street, NE
Atlanta, GA 30308

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December 1982

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PREFACE

The Environmental Protection Agency (EPA) has published a number of Control Techniques Guideline (CTG) documents to inform regional, State, and local air pollution control agencies of technology available for reducing emissions of volatile organic compounds (VOC) from existing industrial sources. These documents are used by regional, State, and local air pollution control agencies for development of regulations necessary to attain and maintain the National Ambient Air Quality Standard (NAAQS) for ozone.

States which have recieved extensions beyond December 31, 1982 to attain the NAAQS for ozone are currently required by the Clean Air Act to submit revised State Implementation Plans (SIP's) to EPA by July 1, 1982. These revisions will generally take the form of additional regulations to reduce VOC emissions from industrial sources. Further, the 1982 ozone policy requires regulation development for all VOC sources that have a potential to emit 90 megagrams (100 tons) per year or more. Since the EPA cannot publish CTGs for all affected source categories, some VOC regulations will have to be developed using information sources other than CTGs. To this end, this technical information document will supply information needed for regulatory development for source categories not previously covered by CTGs.

The information contained in this document is based on contractor evaluation of the existing emission points and processes for those plants cited in this document. This document is as detailed and thorough as financial and time constraints allow. However, source specific information may come to light during the regulatory development process that requires further evaluation and consideration when determining the appropriate level of control for these sources. The final RACT determination should be made by the state after considering this document and other specific factors for these facilities.

The format of regulations developed from this document will be the option of the regulatory agency. They may take the form of operating requirements, mass emission limits, equipment specifications or a combination of the three. For example, under the section on aluminum rolling mills, the state may wish to specify a mass emission limit instead of specifying a specific lubricant substitution. Such an approach would allow the affected source to develop their own control strategy. This approach was used in California and lubricant substitution was used to meet the mass emission limit.

ABSTRACT

This report details the findings of a study performed by Radian Corporation for the Air Programs Branch of the U. S. Environmental Protection Agency - Region IV, the Nashville Metropolitan Health Department, and the Air Pollution Control District of Jefferson County. The purpose of the study was to examine several site-specific volatile organic compound (VOC) emission sources in Louisville, Kentucky and Nashville, Tennessee to determine if reasonably available control technology (RACT) is being applied to control VOC emissions. Reasonably available control technology is defined as the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility. It may require technology that has been applied to similar, but not necessarily identical, source categories. In source categories where VOC controls were found, these controls were evaluated to determine if they constituted RACT. In source categories where no VOC controls were used, candidate control options were identified that could potentially be RACT. Factors considered in the determination of a candidate RACT control option included the VOC removal efficiency, the resultant environmental impacts, and the economic cost of the control mechanism. This document reports the RACT determination results for two aluminum rolling mill lubricant sources in Louisville, and a furniture coating plant and one fiberglass boat builder in Nashville. In addition to these three source categories, five others were examined for the purpose of determining RACT. These five sources were determined to presently have RACT in place and, therefore, are not included in this document. Summary memoranda detailing why RACT is in place were prepared for each source and forwarded to EPA-Region IV. The RACT-in-place sources include a calcium carbide acetylene plant, a neoprene rubber plant, an acrylic polymer plant, a cracker manufacturing plant, and another furniture coating plant.

The aluminum foil rolling operations at Reynolds Metals and Anaconda Aluminum in Louisville emit 2600 Mg (2900 tons) and 630 Mg (700 tons) per year of VOC, respectively. The cause of the VOC emissions at both plants is vaporization of the kerosene-based mixtures used to cool and lubricate the aluminum rolling mills. Currently, the VOC emissions from Reynolds and Anaconda are uncontrolled except for the use of hoods to protect worker health and safety and VOC mist eliminators for opacity control. Both absorption and adsorption add-on controls and a process modification were examined as potential methods to control rolling mill emissions. The most promising control alternative, with a potential to be RACT, was identified as the substitution of a linear paraffin oil for the kerosene-based rolling lubricants presently used. A similar lubricant change in another U. S. aluminum rolling mill plant has resulted in an overall plant VOC emissions reduction of 65 percent.

The furniture coating process at Kabinart Corporation in Nashville, Tennessee has VOC emissions of 140 Mg (155 tons) per year. The source of VOC emissions at this facility is evaporation of organic solvents from the coatings used to finish the furniture. Currently, all VOC emissions generated by the plant are uncontrolled. For Kabinart the implementation of automatic electrostatic spraying was determined to be the best available control for RACT consideration. In addition, waterborne stains were investigated because of their potential use at a later date even though Kabinart determined that they could not be used at this time. Electrostatic spraying could achieve a plant-wide emissions reduction of 9 percent or 13 Mg (14 tons) per year assuming that its application could reduce coating requirements by 40 percent. The conversion to waterborne stains could potentially result in a 40 percent VOC emission reduction plant-wide.

The Hydra-Sports, Inc. fiberglass boat building facility in Nashville, Tennessee has VOC emissions of 48 Mg (53 tons) per year. In addition, the facility disposes of 44.3 Mg/yr (48.9 tons) per year of spent acetone which evaporates off site. The plant has the potential to emit over 90 Mg (100 tons) of VOC from the molding room and spray booths. The three types of uncontrolled VOC emissions at this facility are styrene emissions from lamination, acetone emissions from cleanup of workers' hands and tools and acetone emissions from disposal of spent acetone. Both incineration and chemical scrubbing were investigated to control styrene and acetone emissions from the molding room and spray booths, however, these controls were determined to be too expensive. Suppressed and low styrene resins were investigated to specifically control styrene emissions. Low styrene resins were recommended in this report as a candidate RACT option for control of molding room styrene emissions. Suppressed styrene resins were not recommended because they were not adequately demonstrated. Best available control for acetone emissions for the molding room consists of modifying the present boat building work practices. These modifications would involve storing acetone in closed containers, limiting the amount of acetone issued (per worker), and requiring all workers to use gloves (to reduce the quantity of acetone needed for cleanup). Commercial recycling of spent acetone is recommended as a candidate RACT control option to control emissions from disposal of spent acetone. The level of acetone emissions reduction achievable through the work practice changes is about 8 Mg (9 tons) per year. The use of low styrene resins reduces emissions by 1.2 Mg (1.3 tons) per year and the use of commercial recycling reduces emissions by 44.3 Mg (48.9 tons) per year. The total VOC reduction potential at the plant is 9.2 Mg/yr or 19 percent of the total plant emissions and 44.3 Mg/yr or 100 percent of the emissions at the waste disposal site.

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SECTION A

ROLLING MILL LUBRICANT CONTROL

1.0 INTRODUCTION AND SUMMARY

1.1 PURPOSE OF DOCUMENT

The purpose of this document is to present the findings of Radian Corporation's investigation of Reasonably Available Control Technologies (RACT) for rolling mill lubricant VOC emissions from the Anaconda Aluminum and Reynolds Metals aluminum cold rolling facilities in Louisville, Kentucky. These two plants were selected by EPA's Region IV office and the Air Pollution Control District of Jefferson County (APCDJC) for evaluation because each of them is responsible for annual VOC emissions in excess of 90 Mg (100 tons). This RACT investigation is based on existing readily available information gathered from emissions inventories, permit files, equipment vendors, previous EPA-sponsored studies, and technical journal publications. Radian visited both the Reynolds and Anaconda facilities and obtained practical first-hand information from the plants' engineering staffs. Officials from the APCDJC participated in the plant meetings and provided useful information during the study.

The first part of this document consists of a discussion of the aluminum cold rolling industry and rolling mill lubrication. Lubricant VOC emissions at the Louisville plants are quantified, and factors affecting these emissions are discussed. The applicability of individual VOC control technologies to the source specific plants is investigated. The remainder of the document presents environmental impact and cost analysis considerations for the potential RACT control techniques. The technical information provided in this document will serve as a basis for regulatory action.

1.2 SUMMARY

Anaconda Aluminum and Reynolds Metals operate aluminum cold rolling plants in Louisville, Kentucky. Volatile organic compound (VOC) emissions from the two facilities originate from the kerosene-based hydrocarbon mixture used to cool and lubricate the rolling mills. The air pollution control devices currently employed at the plants are designed to reduce mist and visible emissions and do not control the overall VOC vapor emissions from the mills. Three VOC control technologies were identified as being potentially applicable to the Louisville rolling mill facilities: lubricant substitution to a linear paraffinic base oil, exhaust gas purification using an oil absorption system, and exhaust gas purification using a carbon adsorption system. Based on the information available to Radian, the environmental impacts resulting from the application of these controls were assessed and a cost analysis was performed for each control option. From these investigations it was concluded that the substitution of a linear paraffin oil for kerosene has the greatest potential to be RACT at both the Anaconda Aluminum and Reynolds Metals plants. The fact that this substitution has been demonstrated to reduce emissions in one plant in the United States and that the lubricant is currently used in Spain indicates that implementation of the lubricant substitution should be possible for some of the mills.

2.0 PROCESSES AND POLLUTANT EMISSIONS

2.1 GENERAL

The rolling of aluminum is an important step in the conversion of aluminum raw materials into many consumer aluminum products. The primary objectives of a metal rolling operation are to reduce the thickness of the metal work piece and to form it into a useful shape. There are two basic types of rolling processes, hot and cold rolling; both are used in the aluminum industry. Aluminum hot rolling is performed above the recrystallization temperature of the alloy being processed, generally within the range of 300 to 480°C (572 to 896°F).[1] It is used to produce bars, rods, plate, and sheet directly from cast aluminum ingots. Cold rolling is performed at temperatures below 100°C (212°F)[2] and is used mainly in the production of light-gauge aluminum sheet and foil.

In the manufacture of very thin aluminum sheet and foil, hot mills are used to reduce the thickness of cast ingots to gauges on the order of 2.6 mm (0.1 inch) to 4.0 mm (0.16 inch). The products of these mills are further processed via cold rolling. Foil as thin as 0.0064 mm (0.00025 inch) is produced.[4] Cold rolling is used in the final stages of aluminum foil manufacture because it allows for the production of materials with superior surface properties and narrow dimensional tolerance relative to the products of hot rolling.[3] The ultimate products of the aluminum cold rolling industry include food wraps, packaging materials, containers, and backing for insulation materials. The major companies involved in aluminum rolling operations in the United States are the Aluminum Company of America (ALCOA), Reynolds Metals, Anaconda Aluminum, and Kaiser Aluminum. Geographically, the industry is distributed fairly evenly throughout the United States.

The Reynolds Metals and Anaconda Aluminum plants in Louisville, Kentucky produce aluminum foils of varying thickness from coiled light-gauge aluminum sheet. Both plants operate in the batch mode. Each coil is fed through a cold rolling mill and is then recoiled on the opposite side of the mill. Multiple passes through a particular mill are often used to achieve the desired thickness reduction.

The Anaconda Aluminum plant began production in the early 1940's. The 15 cold rolling mills in operation produce aluminum foil for use in products such as finstock for air conditioning condenser, and evaporator units; light-gauge foil for container manufacture; and light-gauge foil for packaging. The plant receives coiled sheet of about 0.66 mm (0.026 inches) in thickness and produces foils ranging in thickness from 0.15 mm (0.006 inches) to 0.0064 mm (0.00025 inches). In 1980 the amount of aluminum processed at the plant was 24,800 Mg (27,500 tons). The plant has a total production capacity of 33,800 Mg (37,500 tons) of rolled aluminum per year.[5]

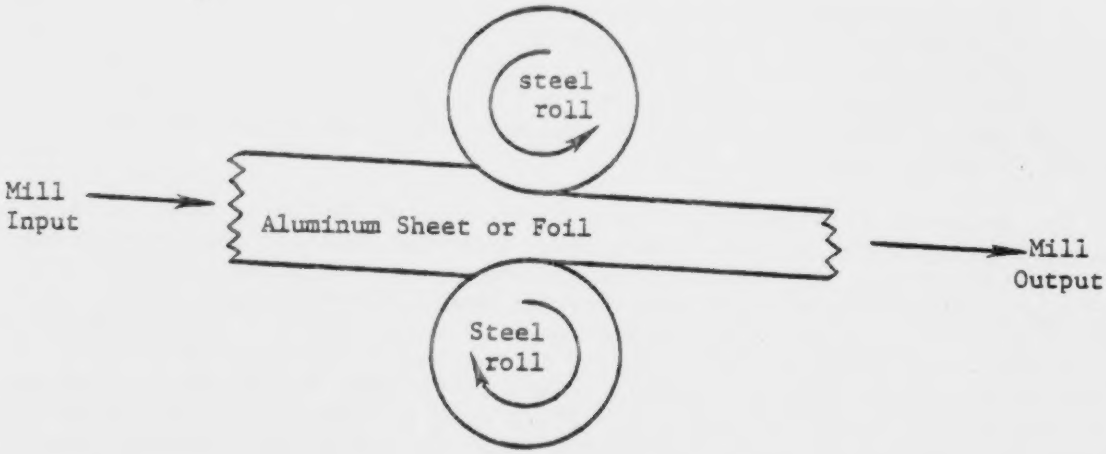
The Reynolds Metals aluminum rolling plan began operation in 1926. The plant maintains 19 rolling mills that produce foil overwraps, aluminum containers and trays, foil-lined cartons, and foil pouches. Coiled aluminum sheet of 1.14 mm (0.045 inch) thickness is cold rolled to thicknesses ranging from 0.089 mm (0.0035 inch) to 0.0064 mm (0.00025 inch).[6] According to permit data, the Reynolds plant processed 313,000 Mg (347,800 tons) of aluminum in 1980. "This processing rate accounts for the fact that on average each pound of metal undergoes 5 rolling mill passes. The actual rated production capacity for the Reynolds plant is 56,750 Mg (62,500 tons) per year.[7,7a]"

2.2 FACILITIES AND THEIR EMISSIONS

This section consists of three parts. First, a general description of aluminum foil manufacturing is given in order to provide necessary background information. Second, a discussion of rolling mill lubrication is included that emphasizes the importance of lubrication with respect to product quality and mill speed. Finally, rolling mill lubricant emissions are discussed and quantified.

2.2.1 Rolling Mill Process Description

Aluminum sheet and foil are cold rolled on either two-high or four-high rolling mills. A schematic diagram of the local metal deformation process on a two-high mill is shown in Figure 2-1, and a four-high, single stand (i.e., one set of rolls) rolling mill with auxiliary equipment is shown in Figure 2-2. The steel work rolls are arranged vertically, and the aluminum is fed horizontally between the rolls at a rate that ranges from about 180 to 1220 m/min (600 to 4,000 ft/min). The roll force is applied perpendicular to the surface of the aluminum. Frictional forces that develop between the rolls and the work piece carry the sheet or foil through the mill. Deformation occurs in two dimensions such that the work piece is flattened



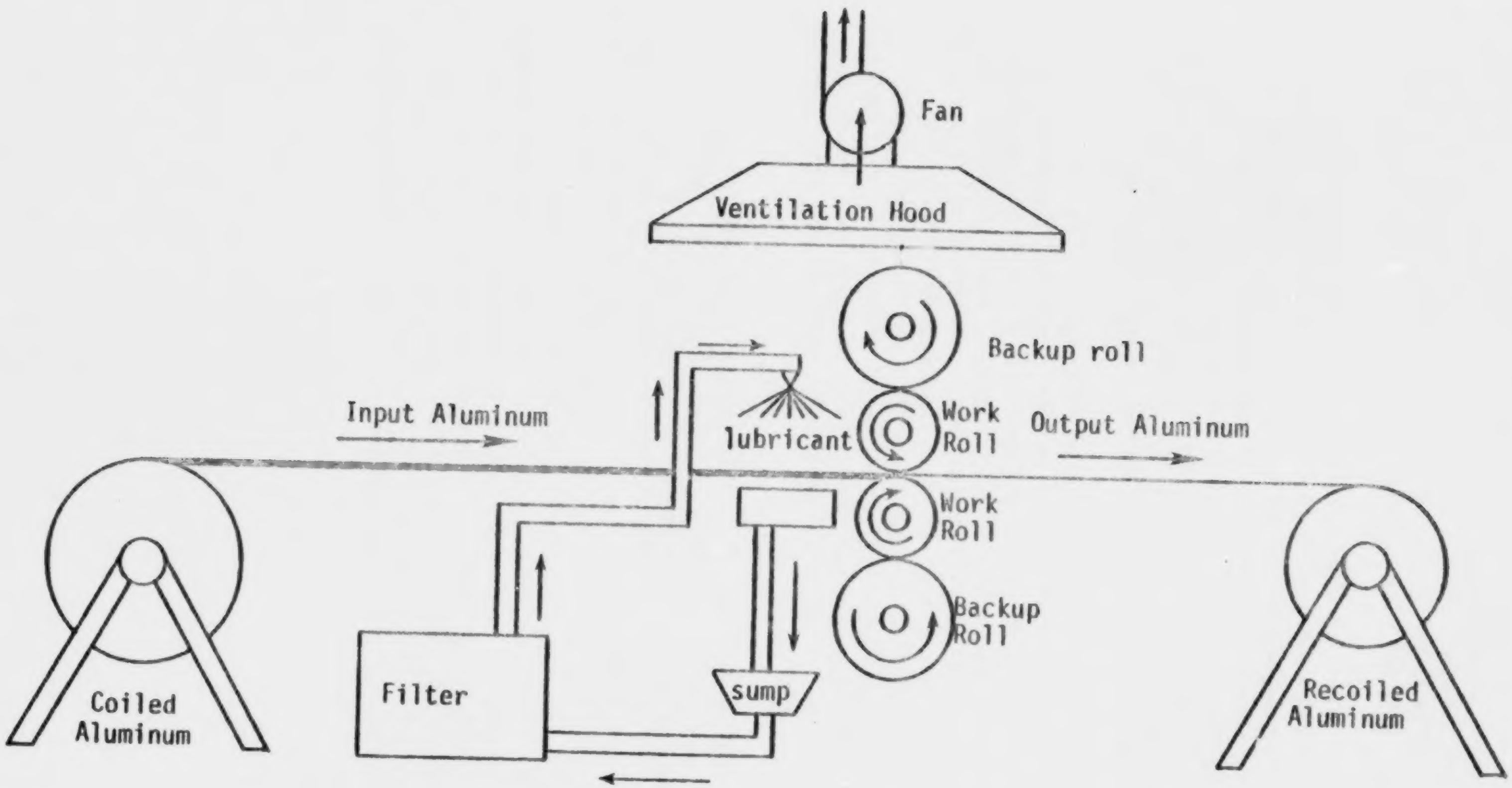

Fan
Ventilation Hood
Backup roll
Input Aluminum
lubricant
Work Roll
Output Aluminum
Work Roll
Backup Roll
Filter
sump
Coiled Aluminum
Recoiled Aluminum

Figure 2-2. Schematic diagram of a four-high, single-stand aluminum rolling mill.

and elongated but not widened upon passage through the rolls. The work rolls are typically 0.76 m (30 inches) to 1.27 m (50 inches) wide regardless of the mill type, but their diameter is variable. The diameter of the work rolls is about 0.61 m (24 inches) for a two-high mill and between 0.25 m (10 inches) and 0.36 m (14 inches) for a four-high mill; the diameter of the back-up rolls for a four-high mill is approximately 0.76 m (30 inches).

Each mill is provided with equipment for handling and coiling the metal. Tension is applied to the work piece during the rolling operation to reduce the mechanical load required for deformation. The temperature of the rolls during each of the cold rolling steps is maintained below about 100°C (212°F) by the application of a hydrocarbon-based lubricant. The lubricant cools the rolls and minimizes excess friction between the strip and the roll. The lubricant is supplied to the rolls in excess, and the overflow is collected, cooled, and filtered before being recycled.

The rolling operation is performed in several stages. The intermediate-gauge coiled sheet that serves as the input to the plant is first sent to a breakdown mill, which is designed to achieve the maximum thickness reduction per mill pass (50 to 65 percent). When the metal has been reduced to the approximate desired thickness, finishing mills are used to improve the surface quality of the foil and to accomplish the final thickness reduction. Finishing rolls are carefully machined and highly polished so that a narrow dimensional tolerance and a bright finish can be obtained for the final product. In the production of very thin foil, two layers of aluminum are often rolled simultaneously on the last pass through the finishing mill (pair rolling).[4]

Following the rolling operation, the aluminum foil is sent to an annealing oven that is generally operated between about 316°C (600°F) and 343°C (650°F).[9] Annealing is carried on at temperatures up to 850°F in some cases. The purpose of the annealing step is to relieve the strain hardening induced by the cold working process and to vaporize or burn off the residual lubricant oil present on the aluminum foil. This is accomplished by heating the aluminum above its recrystallization temperature, thereby allowing for grain growth in the metal microstructure. Lubricants are generally chosen such that their 90 percent distillation endpoint is exceeded during annealing,[9] thereby allowing most of the residual oil to vaporize from the metal surface. The net result of the annealing process is an oil-free product with improved ductility. The annealed foil is either cut to size and packaged or shipped elsewhere for further fabrication.

2.2.2 Rolling Mill Lubrication

Proper lubricant selection is a key variable in producing high quality aluminum foil at high rolling speeds. Mill operators try to maximize throughput by running the mills as fast as possible. High rolling speeds lead to large amounts of heat generation at the roll nip (the aluminum/roll interface). Heat is generated by friction between the aluminum strip and the steel roll as well as by dissipation of mechnical energy during the deformation process. This heat must be removed from the rolls if good product quality is to be maintained because excess heat will cause bending of the rolls and the product thickness will be uneven. Rolling mill lubricants cool the roll surface by reducing friction and transporting heat away from the nip area.

Physical properties relevant to the selection of a lubricant include viscosity, boiling point range, vapor pressure, heat capacity, heat of vaporization, and sulfur content. The most important chemical properties are oxidation resistance, staining tendency, chemical composition, and flash point. Additionally, a lubricant considered for use in the production of materials (such as aluminum foil) that may have incidental contact with foods must be approved by the U.S. Food and Drug Administration (FDA). To qualify for use under FDA rules, an oil must satisfy Sections 3620 and 3910 of the Code of Federal Regulations, Title 21, Part 178, which among other things require that the total residual lubricant remaining on the aluminum product be less than 0.0023 mg per square centimeter (0.015 mg/in^2) of food contact surface, and meet certain maximum ultra violet absorbance limits per 5 cm of optical path length.[10]

Kerosene-based petroleum products (a mixture of C_{10} - C_{16} hydrocarbons) have traditionally been used as cold rolling lubricants in the aluminum industry. They are inexpensive and are capable of producing foils with excellent surface finish qualities. Water-based emulsions have better heat transfer properties than the hydrocarbon oils, but at their present stage of development they are not used as aluminum cold rolling lubricants because of their tendency to stain the product surface.[11] Small amounts of additives are commonly used with the base oils to improve the lubricating and load carrying capabilities of the mixutre and to prevent oil souring (oxidation). Polar compounds such as alcohols, fatty acids, and esters have been used as lubricant additives, typically at levels ranging from zero to five percent by weight.[12] The exact composition of the formulations used varies from mill to mill and product to product, depending on the specific rolling objective at hand. For example, high viscosity formulations can be expected to allow for large thickness reductions per pass but they produce foil with a dull surface finish. On the other hand, low viscosity mixtures are not as effective from the standpoint of metal thickness reduction, but they can be used to produce foils with a bright surface finish. The specific formulations employed in industrial practice are generally considered proprietary.

Several lubricant application techniques are used, including spraying, dripping, and flooding. The application method employed depends on the type of foil being produced, the type of mill used, and the mill rolling speed. Plant operators commonly adjust the lubricant flow rate to achieve particular degrees of pruduct quality.[6] In general, high-speed mills require large amounts of lubricant due to the increased rate of heat production at the roll surface. Flood lubrication is preferred when the rolling speed exceeds 60 to 90 m/min (200 to 300 ft/min).[11] The Louisville source categories examined in this study employed both flooding and dripping oil application techniques.[5,6]

After being applied to the rolls, spent lubricant drains into a mill pit and is cooled using plate or tube heat exchangers. Usually the oil flow is passed through wire mesh filters and/or active earth filters before being recycled. The purpose of the filtration step is to reduce the particulate content of the lubricant, which consists mainly of aluminum fines that cause a rough product finish.[11] The extent to which the lubricant cen be reused depends on the mill temperature, the chemical composition of the base oil and additives, the effectiveness of the filtration system, and the type of foil produced. The Anaconda Aluminum and Reynolds Metals aluminum rolling plants considered in this study reported lubricant lifetimes of three months and ten days, respectively.[5,6] Spent oils are usually burned in a plant boiler or are sold at reduced cost as a fuel oil.

2.2.3 Rolling Mill VOC Emissions

VOC emissions from aluminum foil rolling facilities consist of the vapor and aerosol forms of the rolling mill lubricant. Stack emisions are difficult to quantify because of the many factors affecting lubricant inputs and losses at each mill. Figure 2-3 illustrates the various routes of lubricant emissions and inputs in an aluminum rolling mill. The total amount of oil that ends up as emissions can be qualitatively distributed among the following principal emission sources:

- lubricant vaporized at the foil nip or the aluminum surface that is collected by the ventilation hood and sent out the stack
- residual lubricant carried out on foil, eventually vaporized or burned off during annealing (approximately 23 mg/m^2/side)[11]
- lubricant spilled or splashed on floor
- lubricant vaporized from supply sump
- sump lubricant losses to overflow drain.

These loss sources are balanced by three main input sources of lubricant oils:

- fresh makeup oil to the sump
- equipment oil leaks to the sump
- residual oil on the incoming aluminum coil

While it is known that lubricant vaporization is the ultimate source of VOC emission from cold rolling mills, the industry is unable to accurately

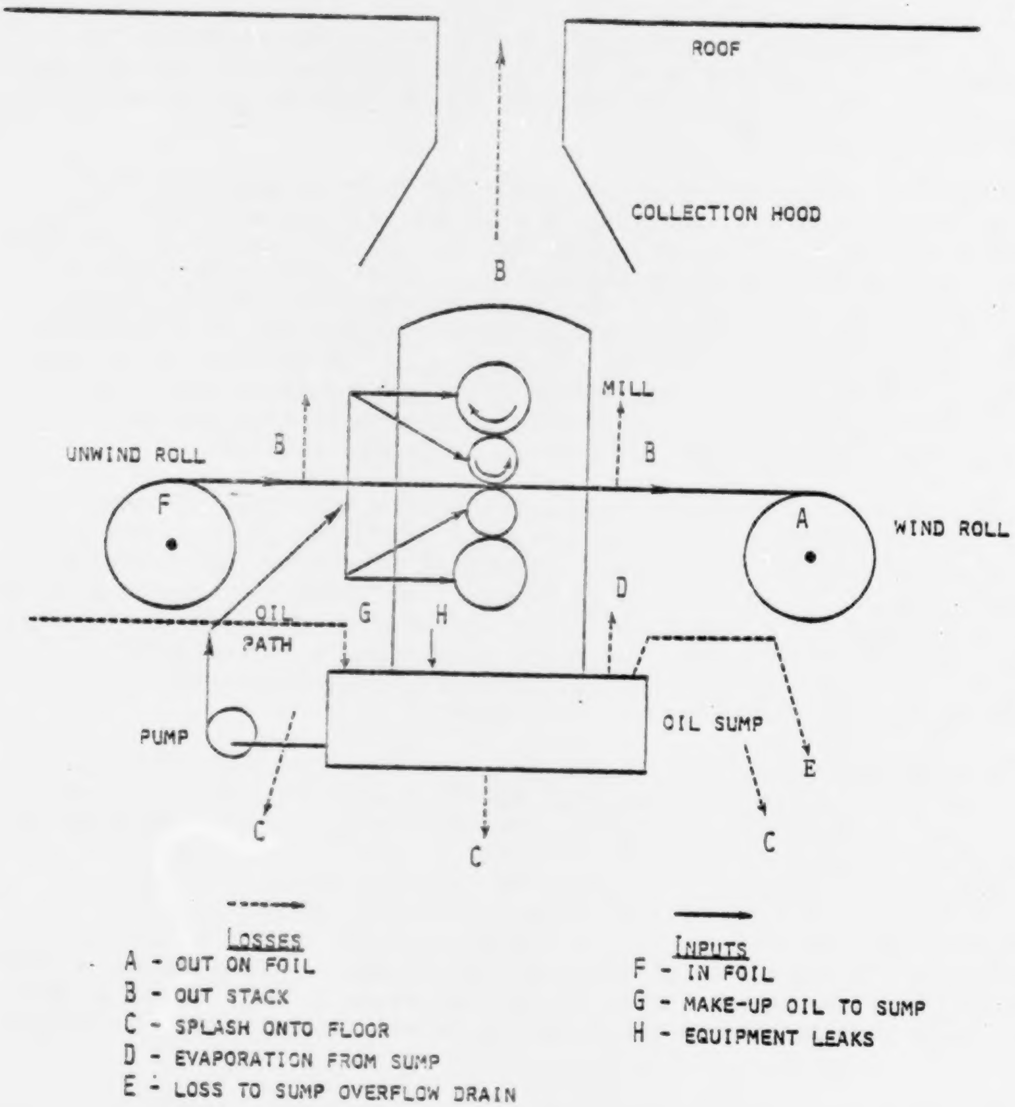

ROOF
COLLECTION HOOD
B
MILL
UNWIND ROLL
B
B
F
A
WIND ROLL
OIL PATH
G
H
D
PUMP
OIL SUMP
E
C
C
C
Losses
A - OUT ON FOIL
B - OUT STACK
C - SPLASH ONTO FLOOR
D - EVAPORATION FROM SUMP
E - LOSS TO SUMP OVERFLOW DRAIN
Inputs
F - IN FOIL
G - MAKE-UP OIL TO SUMP
H - EQUIPMENT LEAKS

Figure 2-3. Lubricant inputs and losses for an aluminum rolling mill.

quantify the relative magnitudes of the sources identified above. It has been estimated that as much as 80 percent of the total apparent kerosene losses from one plant in California are due to fugitive emissions, and only 20 percent are sent out the stack.[2] Other industry representatives believe that fugitive emissions account from about 30 percent of the total losses.[13] Additionally, very little information exists concerning the importance of oil vaporization at the roll nip (the aluminum-steel contact point) where a large fraction of the heat due to friction and mechanical deformation is dissipated.

In addition to the VOC emissions being difficult to quantify, the physical state of the VOC emissions is also not well characterized. Vapor and aerosol forms of VOC are produced, but the relative amount of each type have not been determined. Data obtained by a major manufacturer indicate that between 5 and 50 percent of the total mill emissions may be in the aerosol form[7]; other industry specialists believe that the large majority of emissions is carried out in the vapor phase.[14] At present, an accepted test method for making this determination has not been developed. The aerosol/vapor split may be an important factor when considering the applicability of various add-on VOC emission control devices.

Most aluminum rolling facilities currently use some type of canopy hood for collecting VOC emissions. The hoods are positioned directly above the mills and are designed primarily to capture the VOC vapors and aerosols produced directly by the rolling operation. The predominant function of the ventilation hoods is to reduce workplace concentrations of the lubricants oils to meet OSHA safety requirements. In addition to representing a potential health hazard, oil mist can condense on equipment and other structures, causing corrosion and fire hazards.[15,16]

The most recent estimates of VOC emissions from the Louisville source categories were computed from material balances based on yearly average apparent oil losses from the plants. In 1980, emissions from the Ryenolds Metals plant totalled 2,600 Mg (2,900 tons) of VOC[17], and in 1979, emissions from he Anaconda Aluminum plant totalled 630 Mg (700 tons) of VOC.[5] Expressed in terms of 1980 production rates, emission factors for the Reynolds and Anaconda plants are 0.046 and 0.025 Mg VOC/Mg product, respectively. A comparison of emission factors based on the amount of foil processed, considering the number or rolling passes made per pound of metal, could not be made because this information is not available for the Anaconda plant.

The mill-by-mill exhaust air flow rate data for the Louisville facilities are presented in Table 2-1 and 2-2. Exhaust gas flow rates from the mills range from 85 to 710 m^3/min (3,000 to 25,000 acfm). Based on yearly plant emissions and overall airflow data, the average concentration of VOC in these gas streams is about 30 to 80 ppm.[20] However, the VOC concentration of the exhaust air from individual rolling mills may range from 10 to 400 ppm, depending on the particular mill.[21] Because of this wide range, it may be reasonable to single out certain mills for end-of-stack treatment on the basis of their relatively high VOC concentrations.

TABLE 2-1. INDIVIDUAL MILL EXHAUST AIR FLOW RATES, REYNOLDS METALS

Mill No.	Exhaust air[19] Flow rate (m^3/min)	Exhaust air[19] Flow rate (ft^3/min)
1	560	20,000
2	710	25,000
3	710	25,000
4	560	20,000
5	710	25,000
11	280	10,000
12	280	10,000
13	280	10,000
14	280	10,000
22	280	10,000
23	280	10,000
24	N/A	N/A
25	280	10,000
26	340/4*	12,000/4*
27	340/4*	12,000/4*
28	280	10,000
30	280	10,000
31	280	10,000
32	340/4*	12,000/4*
33	340/4*	12,000/4*

*Mills 26, 27, 32, and 33 are served by a single collection device with a combined air flow rate of 340 m^3/min (12,000 ft^3/min)

TABLE 2-2. INDIVIDUAL MILL EXHAUST AIR FLOW RATES, ANACONDA ALUMINUM

Mill No.	Exhaust Air flow rate (m^3/min)	Exhaust Air[17] flow rate (ft^3/min)
M2	280	10,000
M3	280	10,000
M4	280	10,000
M6	280	10,000
M7	340	12,000
M8	340	12,000
M9	340	12,000
M10	110	4,000
M11	230	8,000
M12	280	10,000
M13	560	20,000
M14	560	20,000
M15	85	3,000
M16	110	4,000

Many factors affect the level of emissions produced by a particular rolling mill within a plant and by an entire plant as a whole, including:

- physical and chemical properties of the base oil and lubricant additives,
- oil temperature,
- amount of heat generated during rolling,
- mill production rate (mill speed),
- magnitude of size reduction per pass,
- type of mill (breakdown, finishing),
- method of oil application and application rate, and
- gas velocity at the face of the collection hood.

The type of product is the most basic consideration since it determines many of the process parameters that are directly responsible for affecting emissions. In particular, the type of lubricant used and the lubricant properties desired are influenced largely by product specifications. The lubricant properties that are most relevant to emissions control are vapor pressure, boiling point range, specific heat, and heat of vaporization. Emissions reduction is favored by lubricants with low volatility, large specific heats, and large heats of vaporization.

The operating temperature of the lubricant is also a very important factor affecting emissions because the vapor pressure of the lubricant, and hence the rate of lubricant evaporation, is strongly temperature dependent. Figure 2-4 illustrates the effect of temperature on the vapor pressure of a typical kerosene. Low operating temperatures are desirable from the standpoint of emissions control due to the fact that the lubricant is less volatile at lower temperatures. Manufacturers of cold rolled aluminum have actively tried to reduce lubricant temperatures to the lowest possible level allowed by product quality considerations.[23] When the lubricant is cooled too far, the sheet shape, surface appearance, and thickness may be adversely affected.

Several of the other factors affecting emissions are interrelated. The quantity of heat generated at the work rolls is increased by increasing either the mill speed or the magnitude of the size reduction per pass. The more heat that is generated, the more oil is required for adequate cooling and the greater is the potential for VOC emissions. Thus, high-speed rolling mills with large thickness reductions per pass would be expected to be characterized by high VOC emission rates.

The coolant application technique can influence overall mill emissions by determining the quantity and the physical state of the applied oil. For example, spraying the lubricant through a nozzle increases the potential for VOC emissions because the oil is partially atomized by the spraying process. The atomized oil is more likely to be vaporized and lost as an emission because of the greater surface area available for evaporation. The application technique is often dictated by product quality.

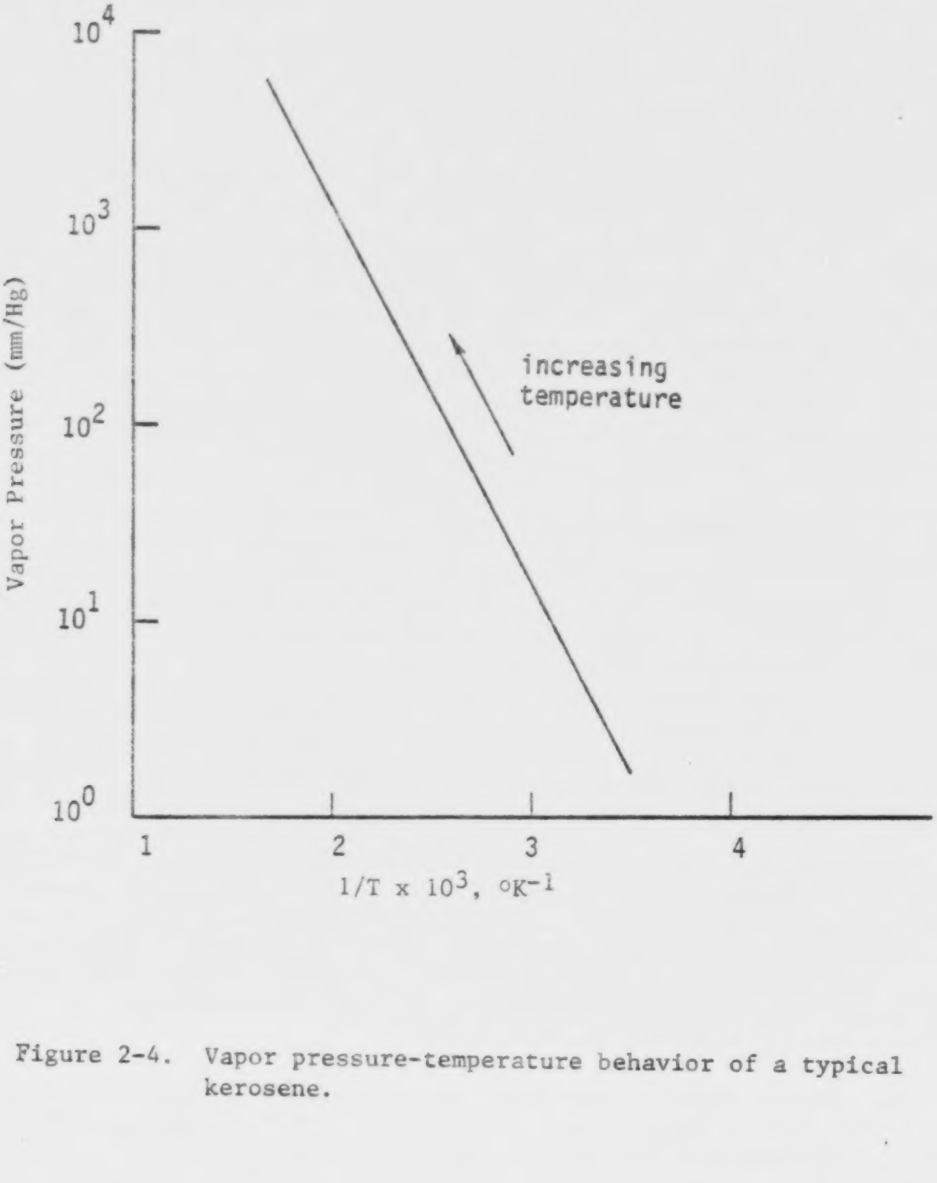


Figure 2-4. Vapor pressure-temperature behavior of a typical kerosene.

The effect of gas velocity at the capture hood on VOC emissions must also be considered. High gas velocities would be expected to improve the convective mass transfer conditions at the oil surface and to increase the degree of oil droplet entrainment in the exhaust gas stream. Both of these phenomena would tend to cause an increase in VOC emissions. The gas velocity in the capture hood should be adjusted to minimize this increase while at the same time insuring the elimination of undesirable workplace oil mist concentrations. Face velocities for the hoods are generally designed within the range of 45 to 90 m/sec (150 to 300 ft/sec).

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3.0 EMISSION CONTROL TECHNIQUES

This chapter discusses the control techniques that are applicable to the control of VOC emissions from the lubrication of foil rolling mills. The chapter is divided into three sections. The first section discusses control techniques that are currently used at the Louisville, Kentucky plants. The second section discusses VOC control techniques that potentially could be applied to the control of emissions from these mills. The last section gives an assessment of the applicability of each of the control techniques considered for RACT determination.

3.1 EXISTING CONTROLS

State and local environmental agencies have historically required only the control of visible emissions from aluminum foil rolling mills. Consequently, rolling mill emission control devices used in the U. S. are designed to reduce mist or liquid particulate emissions and do not control VOC vapor. Several state control agencies have determined that the Busch-Anderson system, which is a combination centrifugal/impaction type mist eliminator, is the best system available for controlling emissions from the newest rolling mills installed in non-attainment areas.[1] This mist eliminator collects 99 percent of all liquid particles greater than 10 microns in diameter but does not collect kerosene vapor.

The emission control devices currently used at the Louisville, Kentucky plants include mist eliminators, rotoclones, centrifugal separators and baffled impaction devices.[1,2] These control devices allow the foil rolling plants to meet the local agency regulation of 20 percent opacity and remove an estimated 50 to 80 percent of liquid particles greater than 10 microns.[3]

Another method of emission reduction that is employed at the Louisville, Kentucky plants is lubricant cooling. Both plants currently operate their rolling mills at the lowest possible temperature that will allow an acceptable product surface quality. Operation at this temperature minimizes the amount of lubricant that is lost to evaporation.

3.2 OTHER APPLICABLE CONTROL TECHNIQUES

There are several emission control techniques that potentially could be used to control VOC emissions from aluminum foil rolling mills. These techniques include both process modifications, and add-on control systems. The control techniques considered, the factors that affect their performance and the applicability of these techniques to the plants in Louisville are discussed in the following sections.

3.2.1 Substitution of Normal Paraffin

One possible means of reducing VOC emissions from aluminum foil rolling mills is the substitution of a normal or linear paraffin oil for the kerosene lubricant currently used. Normal paraffins (C_{11}-C_{14}) are components of the kerosene fraction of crude oils and are separated from kerosene in pure form by molecular-sieve absorption.[3a] Substitution of linear paraffin oil for kerosene may not be applicable to all rolling mills because lubricant formulations differ for different mills. The applicability of lubricant substitution as a VOC control technique will therefore vary on a mill by mill and product by product basis.

Both Reynolds and Anaconda had previously been unable to find an alternate FDA-approved lubricant that would reduce VOC emissions and produce a foil product of equivalent quality.[1,2] However, another foil manufacturer, Kaiser Aluminum, has reduced emissions at one of its California plants by substituting a normal paraffin oil for kerosene.[4] Substitution of the normal paraffin oil resulted in a 63 percent reduction in overall (stack plus fugitive) emissions from the plant, while maintaining equivalent product quality and meeting FDA regulations.[5] The 63 percent reduction was calculated on the basis of a mass balance of lubricant entering and leaving the plant.[6] Total annual emissions from the three foil rolling mills and the Kaiser plant were reduced from 726 to 272 Mg (800 to 300 tons).[25a]

The paraffin oil used in the California plant is a commercially available, high-purity paraffinic solvent containing greater than 98 percent normal paraffins ranging from C_{12} - C_{14} (n-dodecane to n-tetradecane). The oil is used in the food processing industry and is available through several refiners, including Exxon and Conoco.[7,8]

3.2.1.2 Factors Affecting Performance. Factors that will affect the degree of emission reduction achievable through lubricant substitution at a given mill production rate include the operating temperature at which the substitute lubricant will be used and the rate at which the lubricant must be applied.

The operating temperature at which the normal paraffin oil is used will affect the vapor pressure, evaporation rate and heat of vaporization of the oil. Operation at the lowest possible temperature will minimize the evaporation rate and mіximize the heat of vaporization.

The rate at which the lubricant is applied will affect both the amount of evaporation as well as the quantity of lubricant available to remove heat from the rollers. The lubricant application rate is normally adjusted by the mill operator to produce a desired product finish.[1,2] Higher lubricant application rates are generally needed at higher mill production rates because more heat must be removed by the oil.

3.2.1.3 Applicability. There are two primary concerns associated with using linear paraffin oil on any of the rolling mills at the Louisville, Kentucky plans. These two concerns are (1) the applicability of the oil as a base lubricant for rolling a quality foil product and (2) the applicability of the lubricant substitution as an emission control method.

Each of these concerns will be discussed separately in the following sections.

Applicability to the Foil Rolling Process

Available literature data and the successful substitution of linear paraffin oil for kerosene at the Kaiser plant indicate that the foil rolling plants in Louisville, Kentucky should be able to use linear paraffin as a base rolling oil on some of their mills. Aluminum foil producers in Spain currently use n-tetradecane ($C_{14}H_{30}$), a linear paraffin oil, to roll aluminum sheet and foil.[9]

A comparison of the products produced with foil rolled at the Kaiser plant and the Louisville plants indicates that the products have the same or comparable end uses and are of the same thicknesses. The products produced at the Kaiser plant include food service products, such as food wraps and containers for frozen foods. The Kaiser plant also supplies foil for airplane components, duct foil and electronic parts. All of these products have thickness ranging from 0.0007 inches to 0.000285 inches. To produce some of the end products, foil must be printed with inks or laminated to other materials.[9a]

On the basis of a lubricant physical property assessment, there is no apparent technical reason to believe that linear paraffin oil cannot be used as a lubricant for cold rolling aluminum foil. Both Reynolds and Anaconda are currently investigating the substitute lubricant as a means of reducing VOC emissions.[10,11] Application of the normal paraffin substitute on any of the mills at the existing plants in Louisville, Kentucky will require a research and development effort on the part of the companies. Studies to determine customer acceptance of certain foil products rolled with linear paraffin oil will have to be conducted with foil rolled on full-scale mills. Following customer acceptance of foil produced with linear paraffin oil, the substitution could be implemented. Product quality studies may however take 6 to 18 months or longer because of the long lag time between the implementation of lubricant changes and and receipt of feedback on customer product acceptance.[12]

Factors considered in assessing the applicability of linear paraffin as a substitute lubricant for kerosene included the following:

- the expected quality of the finished foil surface,
- the effect of the lubricant on mill production rates,
- the maximum size reduction attainable per pass,
- the FDA acceptability of the lubricant,
- the flammability characteristics of the lubricant, and
- the effect of aluminum alloy type on the lubricant.

These factors and lubricant physical properties affecting these factors will be discussed in this section. Typical physical properties for mineral seal oil, kerosene and a high-purity linear paraffin oil are shown in Table 3-1.

The quality of the surface finish produced with linear paraffin oil should be equivalent to or better than that produced with kerosene.[5,9] The surface finish depends primarily on the viscosity of the oil, and surface

TABLE 3-1. LUBRICANT PHYSICAL PROPERTIES IMPORTANT TO COLD ROLLING OF ALUMINUM

Physical Property	Lubricant		
	Kerosene[a]	Mineral seal oil[b]	High-purity[c] linear paraffin
Boiling Range °C(°F)			
Initial Boiling Point	174 (346)[d]	254 (490)	224 (436)
50%	-	314 (597)	229 (444)
Final Boiling Point	264 (508)	321 (610)	242 (468)
Viscosity cst at 38°C(100°F)	2.5[e]	4.5	1.93
Flash Point °C (°F)	49 - 82[f] (120 - 180)	127 (260)	99 (210)

[a] These properties are for a straight-cut kerosene.

[b] Reference 13.

[c] These properties are for a commercial high-purity linear paraffin - Reference 7.

[d] Reference 14.

[e] Reference 15.

[f] Reference 16.

brightness generally improves with lower viscosity.[15,17] Comparison of the viscosity data shown in Table 3-1 shows that the paraffin oil has a lower viscosity than either of the other oils at the same temperature. The linear paraffin oil therefore potentially could be used at the same operating temperature as the kerosene oils and produce an equivalent or improved surface quality.

The effect that linear paraffin oil may have on current mill production rates is impossible to assess without implementing the lubricant substitution. Foil rolling mills are generally operated at the maximum speed that product quality restrictions will allow so that foil production is maximized. While one investigator has observed that mill production could be increased by substituting n-tetradecane for kerosene, the magnitude of this increase and the initial production rate of the mill were not discussed.[9] The effect that linear paraffin oil has on mill production rates will probably be one of the first variables studied when the lubricant substitution is investigated. Lubricant physical properties that will affect the maximum production rate achievable include the coefficient of friction of the lubricant (with additives), the effect of pressure on the lubricant viscosity, and the heat removal capability of the lubricant.[9,17]

The maximum size reduction obtainable per pass with the linear paraffin oil will depend on the operating temperature and the amount and type of additives used. Size reduction will generally increase with higher viscosity and, as discussed, the viscosity of linear paraffin is lower than that of kerosene.[15] For breakdown mills, where large size reductions are desired and surface finish is less important, a large percentage of additives and a low operating temperature could potentially be used to increase the viscosity and thereby increase size reduction per pass.

For finishing mills, a lower viscosity is desirable and less additive could be used. One laboratory study conducted with 4 inch diameter rolls and 3/8 inch wide metal has shown that there is an unexpected increase in the size reduction per pass for low-viscosity oils, particularly for n-dodecane ($C_{12}H_{26}$).[15] Test data from a study on this scale of mill cannot be applied directly to full-scale mills except from a qualitative standpoint. Depending on whether or not this low-viscosity increase will also occur on the rolling mills in Louisville, Kentucky, the greatest size reductions per pass for finishing mills may be obtained using a minimum amount of additives. The amount of additives will depend on the coefficient of friction required to prevent the appearance of chattering marks (or "herringbone defects") on the foil surface at the operating speed of the particular rolling mills.[17]

As discussed in Section 2.2, the lubricant used for foil rolling must meet certain FDA requirements. At least one oil refiner and a representative of Kaiser have stated that high-purity paraffin oil meets FDA regulations for foil rolling lubricants.[5,18] Linear paraffin oil passes the residual lubricant tests for both weight per unit area and ultraviolet absorbance.[19]

Flammability characteristics of lubricants are usually measured by the lubricant flash point. Comparison of the flash points of the three lubricants in Table 3-1 shows that linear paraffin oil may present a greater fire hazard than mineral seal oil. However, the flash point of the paraffin oil lubricant as applied to the foil rolling mill may be increased by the presence of additives, depending on the amount and type of additives used. A representative of Kaiser has stated that the frequency of fires at the plant has actually been reduced by about 75 percent since the linear paraffin has been used. Special precautions to prevent the lubricant from reaching the flash point may be required to minimize the potential fire hazard if the flash point of the lubricant (with additives) is not above 120°C (248°F).[17]

A direct comparison of the alloys used to make aluminum foil at the Kaiser plant and both Louisville, KY plants could not be made. Although available information indicates that the Kaiser plant and the Anaconda plant use the same alloys (1100, 1145 and 3003), Reynolds claims that their alloy is proprietary.[20a] Nevertheless, in the literature reviewed for this study, there are no discussions indicating that the type of alloy rolled is a major factor to be considered in the selection of rolling mill lubricants. Rolling a harder alloy would probably increase the amount of heat that must be removed and would also reduce the amount of size reduction obtainable per pass for a given input of energy. The pressure exerted on the lubricant would also be increased. Since the viscosity of linear paraffin oil varies less than kerosene with increasing pressure[9], this may be an indication that linear paraffin oil would perform better than kerosene when rolling a hard alloy.

Applicability as a Control Method

The rolling mills at the Kaiser plant are newer mills and operate a similar or higher speeds than the Louisville plants. However, the emission reduction that will be achieved at the Louisville plants cannot be determined on the basis of available data.

An attempt to estimate the emission reduction that may be achieved at the Louisville plants and to explain the 63 percent emission reduction achieved by Kaiser has been made by comparing physical properties of kerosene oils with a linear paraffin oil. However, it was found that the available data on physical properties are insufficient to explain the 63 percent reduction achieved by Kaiser.

Two factors which are of primary importance to the emission reduction achievable through the lubricant substitution are the heat removal capability of the oil and the volatility of the oil. Physical properties affecting these factors are presented in Table 3-2 for linear paraffin, kerosene and mineral seal oil.

Difference in the heat removal capability of linear paraffin oil and kerosene are expected to be the primary factor contributing to the emission reduction achievable through lubricant substitution. On the basis of the specific heat and heat of vaporization data in Table 3-2, the energy required to heat a given weight of lubricant from 38°C (100°F) to 66°C (150°F) and vaporize it is 10 to 30 percent higher for the linear paraffin than for the other two oils.[24] Thus, on the basis of the heat removal capability, assuming that the rolling mills are operated at current speeds, the weight of VOC emitted should be reduced by at least 10 to 30 percent. The achievable reduction is dependent on the operating temperature selected for the linear paraffin and the physical properties of the lubricants currently used at the Louisville, Kentucky plants.

TABLE 3-2. LUBRICANT PHYSICAL PROPERTIES IMPORTANT TO EMISSIONS REDUCTION

Physical Property	Kerosene[a]	Mineral seal oil[b]	High-purity linear paraffin[c]
Specific heat			
J/kg-K (Btu/lb-°F)	2093 (0.50)[d]	2031 (0.485)	2303 (0.55)
Heat of Vaporization at 66°C(150°F)			
J/g (Btu/lb)	256 (110)	221 (95)	323 (139)
Vapor Pressure at 38°C(100°F)			
kPa (Psia)	1.4 (0.2[e])	0.01[f] 0.001	3.4 (0.5)

[a] These properties are for a straight-cut kerosene.

[b] Reference 13.

[c] These properties are for a commercial high-purity linear paraffin - Reference 7.

[d] Reference 21.

[e] Reference 22.

[f] Reference 23.

As stated, these data do not explain the 65 percent emission reduction achieved by Kaiser. One investigator has shown that the specific heat of pure n-tetradecane ($C_{14}H_{30}$) increases with temperature at a faster rate than kerosene.[9] Similar data is not available for the linear paraffin oil used at Kaiser. However, one plausible explanation is that differences in the variation of specific heat and heat of vaporization with temperature and pressure for the linear paraffin compared to kerosene have resulted in the observed emission reduction.

The volatility of a lubricant will depend primarily on its vapor pressure. Vapor pressure varies with temperature and the type of hydrocarbons present in the lubricant. Comparison of the available vapor pressure data in Table 3-2 shows that the vapor pressure of linear paraffin oil is higher than that for the other two oils at the same temperature. However, since the operating temperature of the linear paraffin and the affect of additives on the linear paraffin vapor pressure are unknown, an accurate comparison of the relative evaporation rates of the three lubricants cannot be made. The observed emission reduction achieved by Kaiser seems to indicate that at least for the Kaiser plant the volatility and hence the vapor pressure of the linear paraffin lubricant with additives was lower than the original kerosene-based lubricant.

3.2.2 Absorption Systems

Oil absorption systems (scrubbers) have been used to control aluminum foil rolling mill emissions in Europe, but have not yet been used in the United States.[25] One system used in Kruetzal, West Germany, is called the AIRPURE® system.[26] This system and its applicability to the Louisville plants is discussed in the following sections.

3.2.2.1 Description. A schematic diagram of the AIRPURE® system is shown in Figure 3-1. In this system, rolling mill exhaust gas is contacted countercurrently with a heavy wash oil (or absorber oil) in a screen tray column. The VOC vapors and aerosols are absorbed from the gas stream into the wash oil. The collected lubricant is then separated from the wash oil by means of a two-stage, continuous vacuum distillation system. The separated lubricant is condensed in a heat exchanger and is stored for reuse. Heat for the distillation is supplied by either steam or electricity. The lean wash oil exiting the distillation system is cooled in a heat exchanger and pumped to a tank for reuse in the screen tray column.

The oil absorption system has been demonstrated to be capable of achieving an emission reduction of 90 percent on an inlet VOC concentration of 80 ppm in a gas flow rate of 120,000 m^3/hr (70,000 acfm).[27]

Major factors affecting the performance of oil absorbers on foil rolling mills include the inlet VOC concentration and the amount of lubricant remaining in the lean wash oil. Both of these factors affect the rate of mass transfer of VOC into the liquid. Removal efficiency will generally increase with increasing inlet VOC concentration and will be greatest when the amount of lubricant in the lean wash oil is minimized.

3.2.2.2 Applicability. There is one major factor which must be considered when addressing the applicability of any add-on control devices to the rolling mills in Louisville. This is the severe space limitation at both plants.

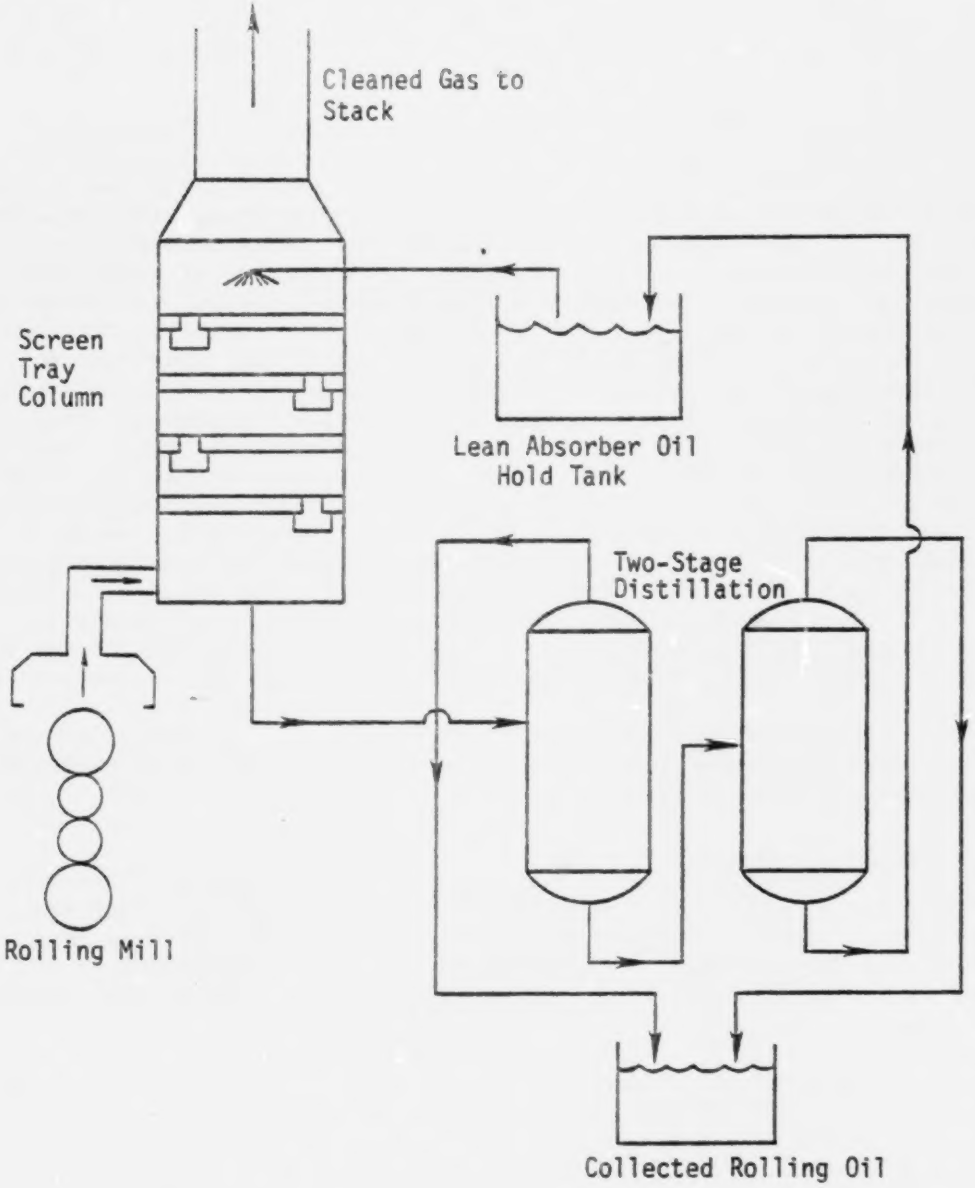
Cleaned Gas to
Stack
Screen
Tray
Column
Lean Absorber Oil
Hold Tank
Two-Stage
Distillation
Rolling Mill
Collected Rolling Oil

Figure 3-1. Schematic diagram of oil absorption system.

A single AIRPURE® system including the absorber and distillation column occupies an area of approximately 12 by 17 meters (40 by 55 feet) and is approximately 6 meters in height (20 feet). An inspection of the plot plan for both Louisville plants shows that floor space of these dimensions is not available.[2,28] One alternative location for the control devices would be on the roof above the mills to be controlled. However, the existing roof structure is inadequate to support a single control system. In order to place a control device on the roof above the mills, a support structure would have to be built. Because of the age and design of the buildings, a self-supporting structure would be needed. This would mean establishing suitable foundations and then raising support columns around the existing mills and mill pits and through the roof. The foundations would have to be designed to take into account the specific soil conditions at each site as well as to avoid the existing mill pits, drain lines, electrical conduits and other utilities. Construction of the foundations for the support structure may necessitate closing down one or several of the rolling mills for considerable periods of time (up to 3 months). The columns would also have to be placed so as not to interfere with existing roof supports, ductwork, and other interferences. In addition, the ductwork for two or more mills would have to be combined and vented to a single add-on control device.

The combination of all of these factors make application of add-on controls less desirable, though not impossible, for control of emissions from the rolling mills at Louisville.

3.2.3 Adsorption Systems

Carbon adsorption systems have not been widely applied to the control of VOC emissions from foil rolling mills. However, one process that employs a combination of carbon adsorption/incineration has been used on a foil rolling operation in West Germany.[29] In addition, one foil manufacture in the United States is currently considering the purchase of carbon adsorption systems for a new plant.

Carbon adsorption systems that could potentially be applied to the control of foil rolling mills include both fixed- and fluidized-bed systems. Fixed-bed systems are typically operated in a batch mode and fluidized systems are continuous. Both types of carbon adsorption systems and their potential applicability to the control of VOC emissions from the Louisville plants are discussed in the following sections.

3.2.3.1 Description - Fixed-Bed. In fixed-bed adsorption, exhaust gas is passed through a bed of granular activated carbon and the VOC vapors are removed by adsorption onto the surface of the carbon. Exhaust gas is passed through the bed for a specified period of time or until the carbon is saturated with VOC and significant breakthrough of VOC vapor occurs. At this time, the gas stream is diverted to a second carbon bed operated in parallel.

The VOC adsorbed on the carbon is desorbed by heating the carbon with steam or heated nitrogen. For rolling mill applications, desorption would most likely be conducted under a vacuum because this would lower the boiling point of the VOC, making desorption easier.[30] The desorbed VOC is condensed and stored for reuse as a rolling oil or used as fuel.

Following desorption, the carbon bed is cooled and dried to improve adsorption. The bed is returned to operation when the other bed has become saturated with VOC.

3.2.3.2 Description - Fluidized-Bed One vendor is currently offering a fluidized-bed carbon adsorpiton system. A schematic diagram of the Purasiv HR® system is shown in Figure 3-2.[31] The system operates with a single column, consisting of one or more adsorption sections at the top and a desorption section at the bottom. Carbon particles pass downward through the column, contacting the gas stream countercurrently and adsorbing VOC vapor. In the desorption section, the hydrocarbons are stripped from the carbon particles by indirect heating with steam or high temperature Dowtherm. The regnerated carbon is cooled and transported back to the top of the column by carrier gas.

3.2.3.3 Factor Affecting Performance. Emission reductions achievable with carbon adsorption systems range from 85 to 99 percent, depending on the specific hydrocarbon adsorbed and the desorption conditions used.[33,34] No data are available on the degree of emissions reduction achievable with carbon adsorbers on VOC emissons from rolling mills.

Important factors affecting performance of carbon adsorbers include the amount of entrained VOC liquid in the inlet gas and the buildup of high boiling compounds in the carbon bed. VOC liquid in the gas stream will needlessly consume carbon adsorption capacity and will cause a need for frequent regeneration of the carbon. VOC liquids in the gas stream must therefore be removed upstream of the adsorber with some type of mist eliminator.

A percentage of high boiling compounds in the gas stream will be adsorbed on the carbon bed and will not be removed during vacuum or steam regeneration. This constant buildup of high boiling compounds, or heel, remaining on the carbon will greatly reduce operating capacity and will eventually cause a need for replacement and/or reactivation of the carbon. Methods of reducting heel buildup include desorption under vacuum and a carbon "guard bed" that acts as a sacrificial device that is replaced more often than the entire bed.[35]

3.2.3.4 Applicability to Louisville Rolling Mills. The retrofit considerations discussed in Section 3.2.3.2 on oil absorption systems also apply to the application of carbon adsorption to the existing rolling mills in Loiuisville, Kentucky. Space limitations inside the plant would require that the carbon adsorption systems be installed on the roofs of the buildings and the existing roofs will not support the weight of the carbon adsorption systems.

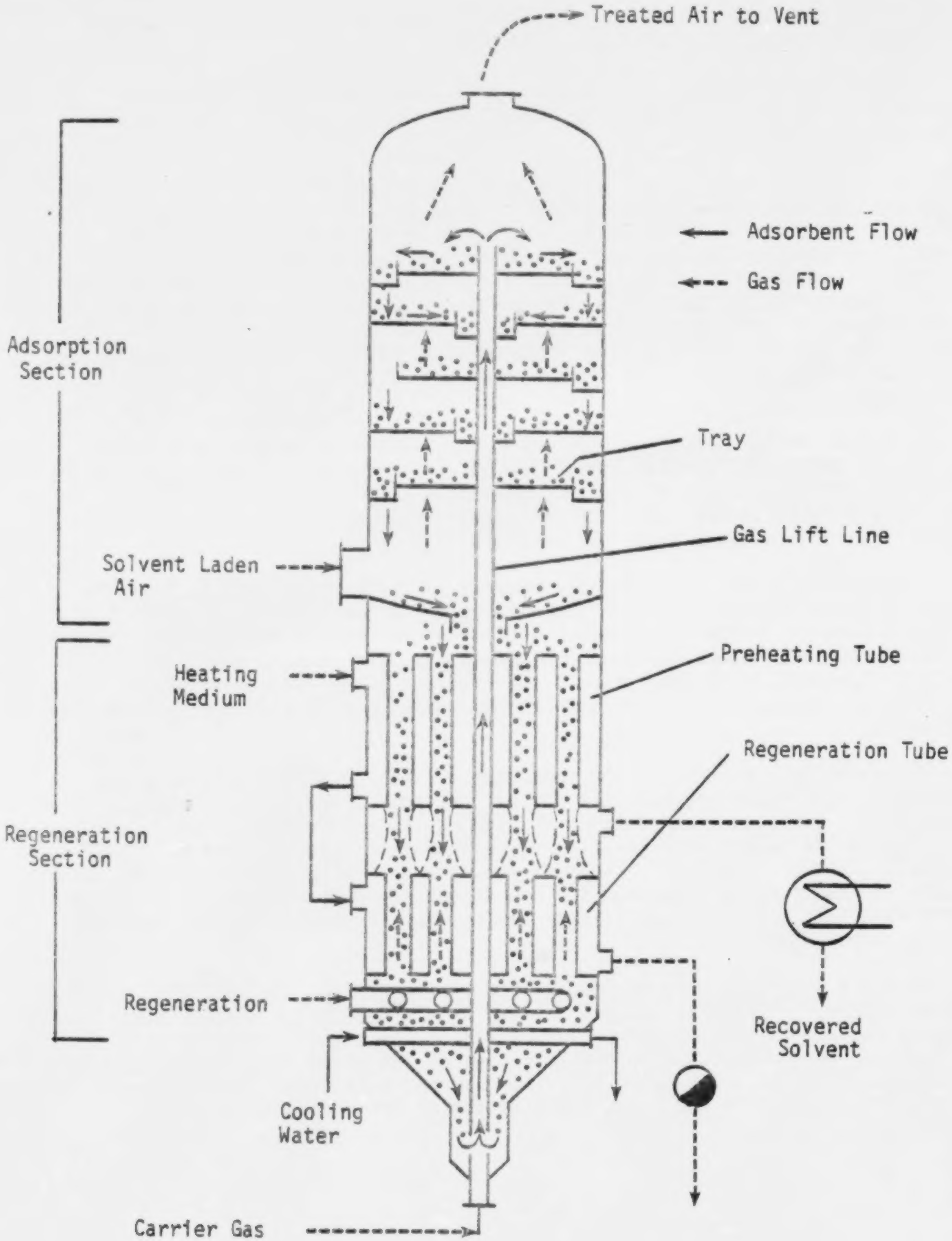
Treated Air to Vent
Adsorbent Flow
Gas Flow
Adsorption Section
Tray
Gas Lift Line
Solvent Laden Air
Preheating Tube
Heating Medium
Regeneration Tube
Regeneration Section
Recovered Solvent
Regeneration
Cooling Water
Carrier Gas

Figure 3-2. Schematic diagram of fluidized-bed carbon adsorption system.

3.3 SUMMARY OF EMISSION CONTROL TECHNIQUES

The technologies considered for the control of the foil rolling mills in Louisville, Kentucky included:

- lubricant substitution,
- oil absorption, and
- carbon adsorption.

Of the three control techniques considered, substitution of a linear paraffin oil for the kerosene-based lubricant currently used appears to have the greatest potential to be RACT. The fact that this substitution has been demonstrated at one plant in the United States and that the lubricant is currently used in Spain indicates that implementation of the lubricant substitution should be possible for some of the mills. However, an accurate prediction of the emission reduction that will be achieved cannot be made on the basis of available data. Potential environmental impacts and the costs associated with implementing this control technique will be discussed in the next two chapters.

Application of the other two control techniques should be possible from a technical standpoint but appears less desirable and cost prohibitive for the existing plants because of space limitations. Oil absorption has been well demonstrated on foil rolling mills in Europe. Carbon adsorption is well demonstrated for VOC control but no performance data is available for carbon adsorbers controlling VOC emissions from rolling mills. Due to a possibility that a site specific cost and architectural engineering analysis may prove either of these systems to be cost effective for rolling mills with high VOC emissions, the environmental impacts and costs associated with both of these systems will also be discussed in the next two chapters.

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4.0 ENVIRONMENTAL IMPACTS

The environmental impacts associated with the potential RACT options identified in Chapter 3 are presented in this chapter. Primary impacts (those directly attributable to the addition of a control system) and secondary impacts (those which are indirect or induced as a result of adding a control system) are discussed. In addition to environmental considerations, the energy impacts associated with the use of add-on VOC control systems will also be presented.

4.1 AIR POLLUTION

As discussed in Chapter 3, both add-on control devices and a rolling mill lubricant change have been proposed as RACT options for aluminum rolling mill VOC emissions. The air pollution impacts of each of these control techniques is discussed separately in the following sections.

4.1.1 Impacts Associated with Using a Substitute Rolling Lubricant

The quantification of the potential emissions reduction achievable in Louisville rolling mill plants by changing the rolling lubricant is difficult because of the many plant-specific and mill-specific process variations that influence emissions. Factors affecting emissions and the applicability of substitute lubricants are discussed in detail in Chapters 2 and 3. Potential emission reductions achievable through a lubricant changeover have, however, been estimated based on a comparison of several key physical properties of the current oils in use and the candidate replacement oil. The emission reduction figures presented in this chapter for the Louisville rolling mill plants are based solely on a comparison of the heats of vaporization and heat capacities of the currently-used commercial rolling oils, the substitute linear paraffin oil. A comparison of these parameters indicates that the VOC emission reductions potentially achievable are due to reduced oil boil-off at the nip area. On this basis, the substitution of the linear paraffin oil for commercial aluminum rolling oils could reduce VOC emissions per mill from 10 to 30 percent.[5] In calculating these reductions it was assumed that the application temperature of all the oils was 38°C (100°F). The effect of these percent reductions on the emissions of a typical rolling mill at Reynolds and Anaconda is given in Table 4-1. The plant-wide emissions reduction achievable from a lubricant substitution is more difficult to quantify because a lubricant change may not work on all mills.

TABLE 4-1. EFFECT OF SUBSTITUTE LINEAR PARAFFIN LUBRICANT ON ROLLING MILL VOC EMISSIONS

Plant	Total Number of Mills	Average Emissions of Typical Rolling Mill Mg per yr (tpy)		Potential Emissions with Linear Paraffin Substitution, Mg per year (tpy)		Potential Plant-wide Emissions with Linear Paraffin Substitution, Mg per year (tpy)	
Reynolds Metals	19	138	(153)	96	(107)	1,824	(2,033)
Anaconda Aluminum	15	42	(47)	30	(33)	450	(495)

A Kaiser Aluminum rolling mill plant in California (producing the same foil products as those in Louisville) has recently changed from a commercial aluminum rolling lubricant to a linear paraffin lubricant, and reduced overall plant VOC emissions by 65 percent. The 65 percent reduction was determined based on a material balance test performed at the facility. Both stack and fugitive VOC emissions are included as part of the 65 percent reduction. Kaiser has not encountered any problems with using the substitute lubricant and product quality has been maintained.[6,7,8]

It is not possible to qualitatively determine how well this linear paraffin lubricant would reduce VOC emissions at the Louisville plants because of differences between the operations. The Louisville facilities are much older, they use a different lubricant application technique, and they operate at different process rates. The effect of these different plant conditions on the reduction capability of the linear paraffin can only be determined by testing of the Louisville mills.

4.1.2 Impacts Associated with Add-on Control Devices

Lean oil absorption and carbon adsorption add-on control systems could have a significant beneficial air pollution impact if used on Louisville rolling mill plants. An oil absorption technique has been demonstrated to be 91 percent efficient in reducing VOC emissions from aluminum rolling mills.[1] This absorption technique has been applied in at least seven rolling mill plants, however, none of the plants are located in the United States.[1] Assuming an average, long-term removal efficiency for oil absorption of 90 percent, stack VOC emissions could be reduced at Reynolds Metals from 1,800 Mg (2,000 tons) per year to 180 Mg (200 tons) per year and at Anaconda Aluminum from 440 Mg (490 tons) to 44 Mg (49 tons) per year. The total 2,020 Mg (2,240 tons) of VOC emissions potentially reducible from the two plants represents approximately 10 percent of the total VOC emissions from the Louisville-Jefferson County emissions inventory.[2]

Carbon adsorption VOC emission control systems have not been applied to any rolling mill plants in this country. However, the process of adsorbing VOC onto the surface of activated carbon has been thoroughly demonstrated in the literature. Removal rates of VOC have ranged between 85 and 99 percent depending on the design of the system and the VOC concentration of the inlet gas stream.[3,4] Carbon adsorption control systems are capable of achieving a long-term VOC removal efficiency of 90 percent, thereby making adsorption equivalent to absorption as a control mechanism for aluminum rolling mills. The emission reduction figures given above for wet absorption would therefore also apply to adsorption.

4.2 WATER POLLUTION

No water pollution impacts are present under either the add-on control or substitute lubricant RACT option. In the case of oil absorption add-on controls, water pollution does not exist because water is not used as the absorption fluid for the kerosene VOC emissions. Instead of water, a recyclable lean oil is used to absorb the emissions resulting from the vaporization of rolling mill lubricants.

In rolling mill plants where carbon adsorption may be used, water pollution would not result because a vacuum system is applied instead of a steam system to regenerate the VOC-laden carbon beds. Therefore, no steam condensate containing VOC would be present as a potential source of water pollution. A vacuum regeneration system is required because of the high boiling point characteristics of the kerosene vapor emissions.

The use of substitute rolling mill lubricants would not result in any form of water pollution.

4.3 SOLID WASTE POLLUTION

The only RACT option that would result in a solid waste pollution problem is the use of carbon adsorption. During normal operation of the carbon system the efficiency of the carbon in the beds gradually degrades to such a level that replacement is required. A quantitative estimate of the annual solid waste load from a rolling mill control system is difficult to make, because no data have been developed that illustrate the useful performance life of activated carbon that is adsorbing the high boiling point kerosenes and additives (esters, saponifiers) that are characteristic of rolling mill operations. Without knowing how frequently the carbon has to be replaced, the annual solid waste load to the environment cannot be accurately determined. A leading manufacturer of adsorption systems estimates, however, that 0.08 kg (0.175 lb) of carbon per acfm of gas flow would be required in a bed that is used to control rolling mill emissions. Assuming a replacement frequency of once a year, a 2,550 m^3/min (90,000 acfm) system would have a solid waste load of 7.1 Mg (7.8 tons) per year and a 1,840 m^3/min (65,000 acfm) system a waste load of 5.1 Mg (5.7 tons) per year. It is highly probable that only minimal actual solid waste pollution would occur from bed replacement because the spent activated carbon could be reactivated by the supplier and reused thereby resulting in no discharge of carbon solid waste to the environment.

4.4 ENERGY IMPACTS

The RACT options that would cause an energy impact would be the use of oil absorption or carbon adsorption add-on controls. The energy requirements of each control technique are primarily electrical energy to operate fans, pumps, and control system instrumentation. The requirements of both absorption and adsorption are summarized in Table 4-2.

TABLE 4-2. ENERGY REQUIREMENTS OF VOC CONTROL SYSTEMS FOR ALUMINUM ROLLING MILLS

Control Technology	Type of Energy	Purpose	Quantity per Year*
Wet Absorption			
- 2,250 m^3/min (90,000 acfm) system	Electrical	Pumping	1,500 (426,800)
		Power fans	5,580 (1.55 x 10^6
		Distillation heat	7,860 (2.18 x 10^6)
- 1,840 m^3/min (65,000 acfm) system	Electrical	Pumping	1,080 (308,200)
		Power fans	4,030 (1.1 x 10^6)
		Distillation heat	5,670 (1.6 x 10^6)
Carbon Adsorption			
- 2,250 m^3/min (90,000 acfm) system	Electrical	Power fans	3,850 (1.1 x 10^6)
	Fossil-fuel	Desorption heat	4,870 (4.6 x 10^9)
- 1,840 m^3/min (65,000 acfm) system	Electrical	Power fans	2,480 (6.89 x 10^5)
	Fossil-fuel	Desorption	1,600 (1.5 x 10^9)

*Electrical energy is in units of gigajoules and (kilowatt-hours). Fossil-fuel energy is in units of gigajoules and (BTU's).

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5.0 EMISSION CONTROL COST ANALYSIS

The costs associated with the substitution of linear paraffin oil for kerosene are discussed in this chapter. In addition, capital and annualized cost estimates for oil absorption and carbon adsorption systems are presented. The basis for capital and annualized cost estimates are presented in Sections 5.1 and 5.2 respectively. Cost estimates for each of the three control techniques are presented in Section 5.3 and cost effectiveness values for the techniques are presented in Section 5.4.

5.1 BASIS FOR CAPITAL COSTS

Capital costs for the three control techniques were based strictly on recent quotes received from petroleum refiners, equipment vendors and industry representatives. Hence, all costs are based on second quarter 1981 dollars.

Research and engineering costs associated with substituting linear paraffin oil for kerosene were not included in the costs presented in Sections 5.3 and 5.4 because these costs could not be estimated with any accuracy. Kaiser conducted testing on a variety of oils within a period of about 2 years but the costs associated with this testing are not available. Many studies would have to be made prior to implementation of the substitution including: (1) investigation of the proper amount of additives needed to give the desired product quality at reasonable production rates; (2) investigation of the effects of the substitute oil on downstream processing such as annealing, printing and laminating and (3) studies to determine customer acceptance of the foil rolled with the substitute oil. The costs associated with these studies will be highly dependent on the engineering approach used and the length of time required to obtain customer acceptance. This long lag time, which is typically over 6 months, makes development of new products/processes time consuming and costly.

The capital costs for the oil absorption and carbon adsorption systems include equipment costs, installation costs and losses incurred by the plant during installation. Equipment costs for both systems are based on a 153,000 m^3/hr (90,000 acfm) gas flow rate, which is a typical size for systems controlling rolling mill emissions. This flow rate would allow control of at least four rolling mills at the Reynolds plant or six mills at the Anaconda plant.

The capital cost for the oil absorption system is based on an equipment vendor quote received by one foil manufacturer in Louisville.[1] The cost for the carbon adsorption system is based on a vendor quote of $25/cfm for a fluidized-bed system.[2] The fluidized-bed system was selected for the cost analysis because one report has shown that operating costs for this system are less than for fixed-beds.[3]

An exact estimate of retrofit costs could not be made due to the need for a site specific architectural engineering analysis as discussed in Section 3.2.3.2. However, one foil manufacturer in Louisville stated that his experience has shown that the cost of retrofit equipment is usually double the installed cost for a new plant.

Costs associated with plant downtime for the installation of the control equipment were estimated by one foil manufacturer in Louisville, Kentucky to be in the range of $5-10 million for a 4 to 6 week shutdown.[4] This is a base cost for plant shutdown and does not include potential losses due to lost market share.

5.2 BASIS FOR ANNUALIZED COSTS

Annualized costs associated with the substitution of linear paraffin for kerosene cannot be accurately estimated because of the complexity of this control technique. As discussed in Chapter 3.0, the emission reduction that may be achieved through lubricant substitution will vary for individual mills.

In order to illustrate the potential cost of the lubricant substitution, however, a model rolling mill having the characteristics shown in Table 5-1 has been developed. Annual costs for the substitution of linear paraffin at various levels of emission reduction were calculated for this mill assuming (1) an annual interest rate of 12 percent for additional capital required for the purchase of linear paraffin instead of kerosene and (2) a waste lubricant value of $0.70/gal. The results of these cost calculations are presented in Section 5.3.1.

Component costs used to calculate annual operating costs for the oil absorption and carbon adsorption systems are presented in Table 5-2. Annualized costs for the oil absorption system were based on a preliminary process design because data on the actual operating costs of an existing system are currently not available.[6] Details of the preliminary design are presented in Table 5-3.

Annualized costs for the fluidized-bed carbon adsorption system were based on information from the equipment vendor offering this system in the United States.[7] Details of the operating conditions and operating needs of the system used in preparing the annualized cost estimates are presented in Table 5-4.

5.3 EMISSION CONTROL COSTS

5.3.1 Lubricant Substitution

Annualized costs for a lubricant substitution are presented in Table 5-5. These costs are based on the model rolling mill described in Table 5-1 using the calculation procedure presented in Table 5-6.[9] The costs are not intended to represent the total cost of substituting linear paraffin

TABLE 5-1. CHARACTERISTICS OF "MODEL" ROLLING MILL

Item	Specified Value or Condition
Annual emission rate	182 Mg (200 tons)
Lubricant sump capacity	3 m^3 (800 gal.)
Lubricant replacement frequency	every 10 days
Kerosene cost	$1.06/gal.
Linear paraffin cost	$1.97/gal.
Lubricant purchase frequency	once/month
Waste lubricant value	$0.70/gal.

TABLE 5-2. BASES FOR CALCULATING THE PRIMARY COMPONENTS OF ANNUALIZED COST[5]

Component	Unit Cost
Absorber oil	\$1.50/gal
Activated carbon (new)	\$6.50/lb
Carbon regeneration	\$1.00/lb
Utilities	
Electricity	\$0.04/kWh
Cooling water	\$0.10/1,000 gal
Fuel oil	\$0.90/gal
Nitrogen	\$1.00/1,000 scf
Operating labor[a]	\$15/hr
Supervision labor[a]	15% operating labor
Maintenance labor[a]	\$16.50/hr
Maintenance materials	100% of maintenance labor
Taxes, insurance, and administration	4% of capital investment
Capital recovery factor	17.7% (Based on an equipment life of 10 years and effective interest rate of 12%)
Recovery credits	\$0.70/gal of lubricant recovered

[a] Note: All labor costs include plant overhead.

TABLE 5-3. OIL ABSORPTION SYSTEM PRELIMINARY DESIGN USED TO ESTIMATE ANNUALIZED COSTS[5]

Item	Specified Value or Type
Gas flow rate	90,000 acfm
Wash oil	
- flow rate	45 gpm
- heat capacity	0.65 Btu/lb°F
- total inventory	1,225 gal.
Heat generation	electrical
Vacuum pumps (2)	30 hp each
Column pressure drop	10 inches water
Operating labor	3.0 man-hr/shift
Maintenance labor	1.5 man-hr/shift
Operating hours	8,760 hr/yr
Removal efficiency	90 percent

TABLE 5-4. OPERATING REQUIREMENTS AND CONDITIONS USED TO ESTIMATE ANNUALIZED COSTS - FLUIDIZED-BED CARBON ADSORBER[7,8]

Item	Condition or Requirement
Total carbon requirement	175 lb/1,000 cfm
Desorption fuel needs	4,000 Btu/lb of lubricant recovered
Column pressure drop	6 inches water
Nitrogen needs	0.05 scf/lb of lubricant recovered
Carrier gas electrical	12 kWh/hr
Operating labor	0.5 man-hr/shift
Maintenance labor	0.5 man-hr/shift
Operating hours	8,760 hr/yr
Removal efficiency	85 percent

TABLE 5-5. ANNUALIZED COSTS AND COST EFFECTIVENESS FOR LUBRICANT SUBSTITUTION AT VARIOUS EMISSION REDUCTIONS[a]

Emission Reduction	Annual Lubricant Losses Mg/yr	ton/yr	Annual Cost[b] $	Cost Effectiveness $/Mg	($/ton)
10%	163	(180)	69,640	3,830	(3,480)
20%	145	(160)	57,700	1,585	(1,440)
30%	127	(140)	45,770	810	(763)
40%	109	(120)	33,840	466	(423)
50%	91	(100)	21,940	241	(219)
60%	73	(80)	10,010	91	(83)

[a] Costs do not include research and engineering costs for implementing the lubricant substitution.

[b] These costs were calculated using the procedure shown in Table 5-6.

TABLE 5-6 EXAMPLE CALCULATION OF ANNUALIZED COST FOR ROLLING MILL LUBRICANT SUBSTITUTION

Basis:
- one month of operation
- annual emission of 200 tons
- 30 percent emission reduction
- lubricant replacement every 10 days
- 800 gallon sump capacity
- 12 percent annual interest rate for working capital

Total oil purchases = Waste lubricant plus emissions

Total kerosene purchased = 3 (800 gallons) + $\frac{200 \text{ ton}}{12} \left(\frac{299.7 \text{ gal}}{\text{ton}}\right)$

= 7,395 gallons/month

Total paraffin purchased = 3 (800 gallons) + $\frac{0.7 \text{ (200 ton)}}{12} \left(\frac{299.7 \text{ gal}}{\text{ton}}\right)$

= 5,896 gallons/month

Oil cost difference = Paraffin purchased x paraffin cost
- kerosene purchased x kerosene cost

Oil cost difference = (5,896 gallons)(\$1.97/gallon)
- (7,395 gallons)(\$1.06/gallon)

= \$3,776/month

Interest on working capital = oil cost difference x interest rate

= \$3,776/month 0.12/yr $\left(\frac{1 \text{ yr}}{12 \text{ months}}\right)$

= \$38

Total monthly cost = oil cost difference plus interest on working capital

Total monthly cost = \$3,776 + \$38

= \$3,814/month

Annual cost = \$45,768

for kerosene on any mill in Louisville, Kentucky since costs for research and engineering are not included. The costs illustrate that the cost of lubricant substitution has the potential to be a reasonable cost control option, assuming that the achievable emission reduction is high enough.

5.3.2 Add-on Control Systems

The total installed capital cost for the retrofit oil absorption system is $11.9 million. This capital cost includes $4.4 million for equipment and installation at the existing plant and $7.5 million for downtime costs.

The total estimated annualized costs for the oil absorption system are presented in Table 5-7. As shown, the total annualized cost for the system is approximately $2.87 million without recovery credit.

The total installed capital cost for the retrofit fluidized-bed carbon adsorption system is $12 million. This cost includes $4.5 million for equipment and installation at the existing plant and $7.5 million for 5 weeks of plant downtime.

The total estimated annualized costs for the carbon adsorption system are presented in Table 5-8. As shown, the total annualized cost for the system is approximately $2.73 million without recovery credit and is about $140,000 less than the annualized cost for the oil absorption system. This cost is within our error of ± 30 percent and is therefore not significant.

5.4 COST EFFECTIVENESS

Cost effectiveness values for a lubricant substitution are presented with the annualized costs shown in Table 5-5. The potential for the lubricant substitution to be a cost effective method of controlling VOC emissions from rolling mills will be highest for mills with the greatest annual emissions. For mills with high emissions, the required emission reduction needed to obtain a cost savings as a result of lubricant substitution would be lower than for the model case shown in Table 5-5.

Cost effectiveness values with and without product recovery credit are shown in Table 5-9 for each add-on control system and for each of the plants in Louisville, Kentucky. These values are based on the average plant emissions per mill. Cost effectiveness values for the oil absorption system are based on the assumption of a 90 percent reduction in stack emissions and the values for carbon adsorption are based on the assumption of an 85 percent reduction.

TABLE 5-7. ESTIMATED ANNUALIZED COSTS FOR OIL ABSORPTION WITHOUT RECOVERY CREDIT

Direct Costs	Annual Quantity	Unit Cost $	Total Annual Cost $
Raw Materials			
Absorber oil	1,348 gal.	1.50/gal.	2,022
Utilities			
Electricity	4.157×10^6 kWh	0.04/kWh	166,280
Cooling water	4.034×10^7 gal.	0.10/1000 gal.	4,034
Operating Labor and Supervision	3,778 man-hr	15.00/man-hr	56,670
Maintenance			
labor	1,643 man-hr	16.50/man-hr	27,110
materials	(100% of maintenance labor)		27,110
Total Direct Costs			283,226
Indirect Costs			
Taxes, Insurance, and Administration	(4% of capital investment)		476,000
Capital recovery	(17.7% of investment, based on 12% interest and 10 yr. life)		2,106,300
Total annual costs			2,865,526

TABLE 5-8. ESTIMATED ANNUALIZED COSTS FOR FLUIDIZED-BED CARBON ADSORPTION WITHOUT RECOVERY CREDIT

Direct Costs	Annual Quantity	Unit Cost $	Total Annual Cost $
Raw Materials			
Carbon Replacement[a]	1,575	6.50/lb	10,238
Carbon Reactivation[a]	14,175	1.00/lb	14,175
Utilities			
Electricity	1.068×10^6 kWh	0.04/kWh	42,720
Fuel[b]	35,556 gal.	0.09/gal.	32,000
Cooling water	2.49×10^7 gal.	0.10/1000 gal.	2,490
Nitrogen	52,000 scf	1.00/1000 scf	52
Operating Labor and Supervision	630 man-hr	15.00/man-hr	9,450
Maintenance			
Labor	548 man-hr	16.50/man-hr	9,042
Materials	(100% of maintenance labor)		9,042
Total Direct Costs			129,209
Indirect Costs			
Taxes, Insurance and Administration	(4% of capital investment)		480,000
Capital Recovery	(17.7% of capital, based on 12% interest and 10 yr life)		2,124,000
Total Annual Cost			2,733,209

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[a] Based on assumption of regeneration once per year with 10% losses.

[b] The adsorber uses a dowtherm® system to heat the bed for desorption.

TABLE 5-9. COST EFFECTIVENESS OF ADD-ON CONTROL SYSTEMS

Plant	Control Method	Without Recovery Credit $/ton of VOC controlled	With Recovery Credit $/ton of VOC controlled
Reynolds[a]	Oil absorption	7,440	7,140
Reynolds	Carbon adsorption	7,500	7,200
Anaconda[b]	Oil absorption	17,700	17,400
Anaconda	Carbon adsorption	16,300	16,080

[a] Calculations based on control of four largest air flows at this plant.

[b] Calculations based on control of six largest air flows at this plant.

5.5 REFERENCES

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SECTION B

FURNITURE COATING

1.0 INTRODUCTION AND SUMMARY

1.1 PURPOSE OF DOCUMENT

The purpose of this document is to present the findings of an investigation of reasonably available control technologies (RACT) for the furniture coating process at Kabinart Corporation in Nashville, Tennessee. Kabinart Corporation was chosen by EPA Region IV and the Nashville Metropolitan Health Department because it has the potential to emit more than 90 Mg (100 tons) of VOC yearly. The RACT investigation is based on existing or readily available information obtained from emissions inventories, permit files, and technical journals. In addition, Radian visited Kabinart and the Nashville Metropolitan Health Department to obtain first-hand information.

Chapters 2 and 3 of the document consist of a discussion of the VOC emissions sources and the factors affecting VOC emissions, a description of the potential emission controls and a determination of the controls that have the most potential to be considered RACT. Chapters 4 and 5 present the environmental impacts and a cost analysis for the controls being considered as possible RACTs. The technical information provided will serve as a basis for regulatory action.

1.2 SUMMARY

Kabinart Corporation in Nashville, Tennessee manufactures low to medium quality wood kitchen cabinets. The VOC emissions from the furniture coating process at this facility are uncontrolled. From investigations into current VOC emission controls, automatic electrostatic spraying was determined to be the best candidate for a RACT selection. Kabinart investigated electrostatic spraying and also investigated the use of waterborne stains. However, from their tests, they determined that waterborne stains could not be currently used because of difficulties encountered in getting a quality finish. Nevertheless, waterborne stains will be presented in this study because of their potential use at a later date if some of these difficulties are reduced or eliminated.

Based on the information provided by Kabinart and additional information collected during the course of the project, the environmental impacts resulting from the application of both of these controls were identified and a cost analysis of each control was done. From these investigations, it was determined that the VOC emissions reduction due to the conversion to electrostatic spraying could range from 13 Mg/yr (14 tons/year) to 1.8 Mg/yr (2 tons/year) depending on the type of system employed and the amount of coating savings. The conversion to waterborne stains could lower emissions by 56 Mg/yr (62 tons/year). The cost of the electrostatic spray conversion could range from $840 to $13,400/ton of emissions reduction. These costs are specific to Kabinart and are on the high end of the expected costs of typical electrostatic spray conversions. For the waterborne stain, the costs would be about $830/ton of emissions reduction assuming that 3 extra sanders would be needed.

2.0 PROCESSES AND POLLUTANT EMISSIONS

This chapter presents a description of the wood furniture industry, its coating process and its VOC emissions sources. The coating process is the final step in the manufacture of wood furniture. In addition, this chapter describes the wood coating process and VOC emissions at Kabinart Corporation.

2.1 GENERAL INDUSTRY DESCRIPTION

The wood furniture industry is classified into six SIC codes. Table 2-1 presents the total number of facilities in each SIC code along with the plant size distribution. Wood furniture is categorized into three generic classes: cabinetry, household furniture, and institutional furniture. These generic classes are further divided into three quality levels: high end, medium end, and low end furniture. A distribution of the three manufactured wood furniture quality levels on a per dollar and per unit basis is shown in Table 2-2.

Kabinart Corporation in Nashville, Tennessee finishes wood kitchen cabinets. It is a small plant with about 25 employees. Kabinart receives partially machined components and raw materials, completes the machining, assembles into units and finishes the final product. The cabinets vary from low to medium quality.

2.2 COATING PROCESS AND EMISSIONS

The focus of this study is the coating process which forms the finish on wood furniture. Typical coatings are stains, washcoat, filler, sealer, glaze and lacquer. They give color and character to the wood, seal the wood pores, and provide a clear protective topcoat on the finish. High quality furniture generally requires about ten different coating applications.[1] Lower quality furniture may require around three to five coating applications. For less expensive furniture, the typical coatings previously described may be replaced by paint, printed material, plastics, and laminated vinyl overlays.[2]

In the wood kitchen cabinet industry (SIC 2434), over half of the cabinets produced are coated in a manner similar to wood furniture. However, the kitchen cabinet industry generally applies fewer coatings. Typical coatings applied to kitchen cabinets are stain, sealer, wiping stain and lacquer. The remainder of the kitchen cabinet industry replaces the coatings by using paint, high pressure laminates, synthetic varnishes, or precoated boards.[2]

2.2.1 Coating Process

The typical furniture industry coating process consists of a series of steps starting with placing a piece of furniture on a conveyer line. As the piece is carried along the line, workers stationed along the line apply the

TABLE 2-1. WOOD FURNITURE INDUSTRY STRUCTURE (1978)[3]

SIC	Industry	Total Number of Plants	Number of Small Plants (<50 employees)	Number of Medium Plants (50 - 249 employees)	Number of Large Plants (>250 employees)
2434	Wood kitchen cabinets	2,065	1,878	160	27
2511	Wood household (except upholstered)	1,800	1,336	307	157
2512	Wood household (upholstered)	1,264	821	368	75
2517	Wood television, radio, phonograph, sewing machine cabinets	73	44	19	10
2521	Wood office furniture	291	216	63	12
2531	Public building and rental furniture	401	282	103	16
	TOTAL	5,894	4,577	1,020	297

TABLE 2-2. DISTRIBUTION OF WOOD FURNITURE BY QUALITY LEVELS (1978)[2]

Quality level	Percentage on a per dollar basis	Percentage on a per unit basis
Low	60	64
Medium	30	28
High	10	8

coatings. The coatings are usually applied with spray guns in a spray booth. There is usually a separate spray booth for each coating. After each coating application, the conveyer carries the piece to the next spray booth. As the piece travels from spray booth to spray booth, it is allowed to air dry. In some cases, there is an oven after a spray booth which provides quicker drying. In addition to the coating application, the furniture may be rubbed, wiped, or sanded between the spray booths to produce the required finish.

Both ovens and spray booths have ventilation systems to remove the organic vapors released from the coatings. Spray booths are required to have high air flows to limit exposure of the spray gun operators to the organic vapors present in the coatings. Ovens do not have the same high air flow requirements. Typical oven exhaust air flows are five times less than the spray booth exhausts.[5]

Kabinart Corporation has two separate finishing lines. A diagram of the coating process on each finishing line is presented in Figure 2-1. The cabinets and drawers are placed on the floor conveyer (cabinet line) and the cabinet doors are hung on an overhead conveyer (door line). Each finishing line applies a stain, sealer, and lacquer. The stain provides a color uniformity and develops wood grain and character. The sealer seals the wood so that the lacquer can be applied. The final step, the lacquer application, provides a deep, clear finish and protects the wood. Four different colors of stain and one type of sealer and lacquer are used. All of the coats are hand sprayed in separate spray booths. Excess stain is wiped off by hand after the spray booth. Table 2-3 presents some characteristics of the different coatings applied at Kabinart.

The spray booths are about 2.4 m (8 ft) high and about 6 to 7 m (20 to 24 ft) long. An exhaust fan at the top of each booth maintains an air velocity of at least 40 m/min (130 ft/min) past the operator because of OSHA requirements. The air flow is then ducted outside the building. The stain spray booths have exhaust air flows of 420 m^3/min (15,000 scfm), while the sealer and lacquer spray booths have exhaust air flows of 280 m^3/min (10,000 scfm). The stain spray booths have eight conventional air atomized spray guns. The sealer and lacquer spray booths each have two airless spray guns which rely on fluid pressures of between 8,300 - 9,000 kPa (1200 to 1300 psi) to atomize the coating.

2.2.2 VOC Emissions

The source of VOC emissions is the organic solvents in the coatings. The main factors affecting VOC emissions are the solvent content of the coatings (generally 75 percent or more) and the transfer efficiency of the coating application equipment.[6] Transfer efficiency is defined as the amount of coating applied divided by the amount of coating sprayed. As the transfer efficiency improves, less coating has to be sprayed to coat the piece thereby reducing VOC emissions. In almost all coating applications, spray guns are used. The transfer efficiency of the spray gun for a certain type of furniture depends mainly on the type of spray gun and equipment maintenance. Most plants in the industry currently use air atomized or airless spray guns.

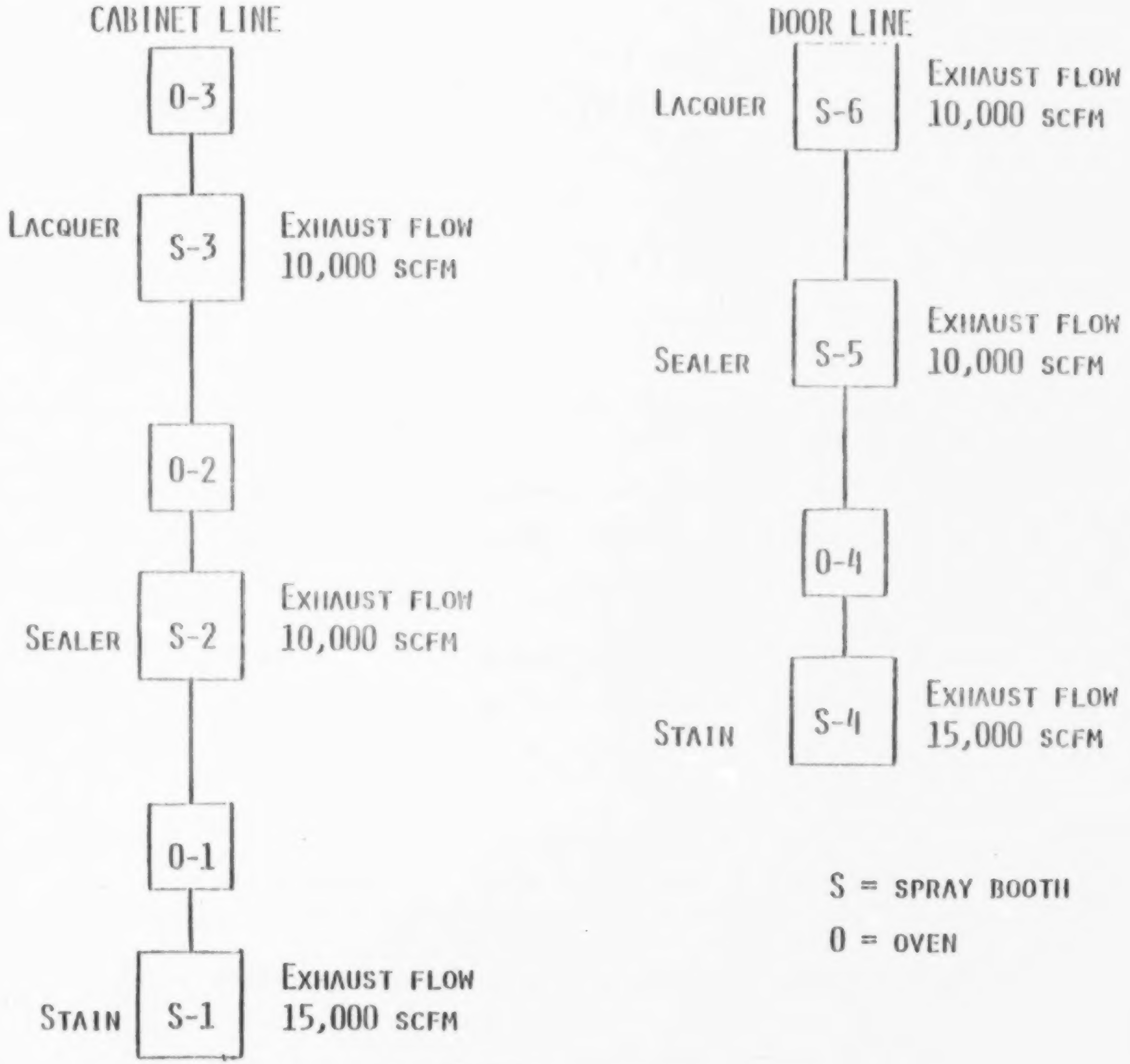
CABINET LINE
0-3
LACQUER
S-3
EXHAUST FLOW
10,000 SCFM
0-2
SEALER
S-2
EXHAUST FLOW
10,000 SCFM
0-1
STAIN
S-1
EXHAUST FLOW
15,000 SCFM
DOOR LINE
LACQUER
S-6
EXHAUST FLOW
10,000 SCFM
SEALER
S-5
EXHAUST FLOW
10,000 SCFM
0-4
STAIN
S-4
EXHAUST FLOW
15,000 SCFM
S = SPRAY BOOTH
0 = OVEN

Figure 2-1. Coating process flow diagram at Kabinart Corporation.

TABLE 2-3. COATING CHARACTERISTICS AT KABINART CORPORATION

Coating Operation	VOC Solvent Content of Coating (Volume %)	Volume Coating Used lit/year	(gal/year)	Density kg/m^3	(lb/gal)	Major Solvent Component
Cabinet Line						
Stain	99	43,100	(11,400)	840	(7.0)	xylene
Sealer	77	39,400	(10,400)	870	(7.3)	toluene
Lacquer	77	32,200	(8,500)	900	(7.5)	toluene
Door Line						
Stain	99	28,800	(7,600)	840	(7.0)	xylene
Sealer	77	26,100	(6,900)	870	(7.3)	toluene
Lacquer	77	21,200	(5,600)	900	(7.5)	toluene

Air atomized guns can achieve around 20 to 40 percent transfer efficiency depending primarily on the type of piece being sprayed. Airless spray guns can usually achieve higher transfer efficiencies than air atomized guns; however, they can be used only on certain types of furniture. Once a spray system has been installed, the coating solvent content and type of spray gun are fixed so the emissions from the coating process in a plant will not vary significantly over time.

Most of the solvent contained in the coatings evaporates in three main locations: the spray booth, the area between spray booths (flashoff area), and the ovens. Table 2-4 shows the percentages of solvent evaporated in each area. One percent or less of the solvent in the coating remains in the "dried" finish and evaporates during handling and processing.[7]

TABLE 2-4. SOURCES OF PROCESS EMISSIONS[7]

	Spray booth	Flashoff area	Oven
Percentage of solvent evaporation (when oven is present after spray booth)	65	15	20
Percentage of solvent evaporation (no oven after spray booth)	65	35	-

Total VOC emissions from the coating process at Kabinart are 140 Mg/yr (155 tons/year). The major emission points are the six spray booth exhausts. Table 2-5 presents the emissions for each of these emission points. The emissions from the flashoff area (fugitive emissions) will be captured by the various spray booth, oven and general ventilation exhausts. Therefore, no emission points for these emissions can be identified. The emissions from the ovens are small (less than 7 Mg/yr (8 tons/year)) and are not discussed further in this report. The emission values presented in Table 2-5 were calculated based on the amount of coatings used because VOC emissions have not been measured. The calculations were also based on the following two assumptions:

- 60 percent of the coatings are applied on the cabinet finishing line and 40 percent are applied on the door finishing line.[8]
- 65 percent of the solvent content of the applied coating evaporates in the spray booth and is captured by the spray booth exhaust.[7]

The VOC concentration of the emissions at each spray booth are also presented in Table 2-5. These concentrations are low due to the high exhaust air flows that are required for worker safety.

TABLE 2-5. SPRAY BOOTH EMISSIONS[a]

	Process No.	Exhaust Air flow rate m^3/min (scfm)	VOC Concentration[b] ppm	VOC Emissions Mg/yr(tons/yr)
Cabinet Line				
Stain booth	S-1	420 (15,000)	110	23 (26)
Sealer booth	S-2	280 (10,000)	120	17 (19)
Lacquer booth	S-3	280 (10,000)	100	14 (16)
Door Line				
Stain booth	S-4	420 (15,000)	70	15 (17)
Sealer booth	S-5	280 (10,000)	80	12 (13)
Lacquer booth	S-6	280 (10,000)	70	10 (11)

[a] The emissions from the ovens are small (less than 7 Mg/yr (8 tons per year each)) compared to the spray booth emissions and are not presented.

[b] VOC concentrations were calculated based on the estimated VOC emissions and the reported air flow rates.

2.3 REFERENCES

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3.0 EMISSION CONTROL TECHNIQUES

This chapter describes three controls that have the potential to reduce VOC emissions from the furniture coating process at Kabinart Corporation. The three controls considered are electrostatic spraying, waterborne coatings and incineration. In this chapter, each control system will be described along with the performance and problems associated with its use in the general furniture industry. In addition the applicability and problems associated with their use at Kabinart will be discussed.

3.1 ELECTROSTATIC SPRAYING

Electrostatic spray equipment has been investigated by Kabinart Corporation because it has the potential to reduce the amount of coating which must be sprayed to finish the product. From their study, Kabinart determined that electrostatic spraying could be used to reduce VOC emissions. The best application would be to use automatic electrostatic spray equipment to spray sealer and lacquer on the door finishing line. The cabinet line and the staining operation would be unsuitable for automatic electrostatic spraying. Kabinart plans to install the automatic electrostatic system on the door line sealer and lacquer spray booths and investigate manual electrostatic spraying on the cabinet line and the door line stain spray booth sometime in the next year.

3.1.1 Description of Electrostatic Spraying

Electrostatic spray equipment supplies a positive charge to atomized coating particles so that they are attracted to a negative or grounded piece of furniture. This attraction improves the coating transfer efficiency. The benefit of an improved transfer efficiency is that less material has to be sprayed to achieve a given coating thickness on the piece.

Figure 3-1 presents a simple diagram of an electrostatic spraying operation. The pieces to be sprayed are usually hung on a grounded overhead conveyer. The conveyer carries the pieces in front of the stationary spray head. The spray head supplies a charge of 60-100 kV and sprays a fine mist of charged coating particles.[1] The electrostatic attraction then pulls the coating particles to all sides of the piece.

When spraying electrostatically, the piece being sprayed should be approximately 30 to 41 cm (12 to 16 in) from the spray device for optimum transfer efficiency. Having the piece any closer than 30 cm (12 in) may cause the system to ground out. If the piece is farther away from the spray device than 46 cm (18 in), the spray may be attracted to other grounds. In addition, the piece should be at least 46 cm (18 in) from other grounds to ensure that it attracts the majority of the coating.[2]

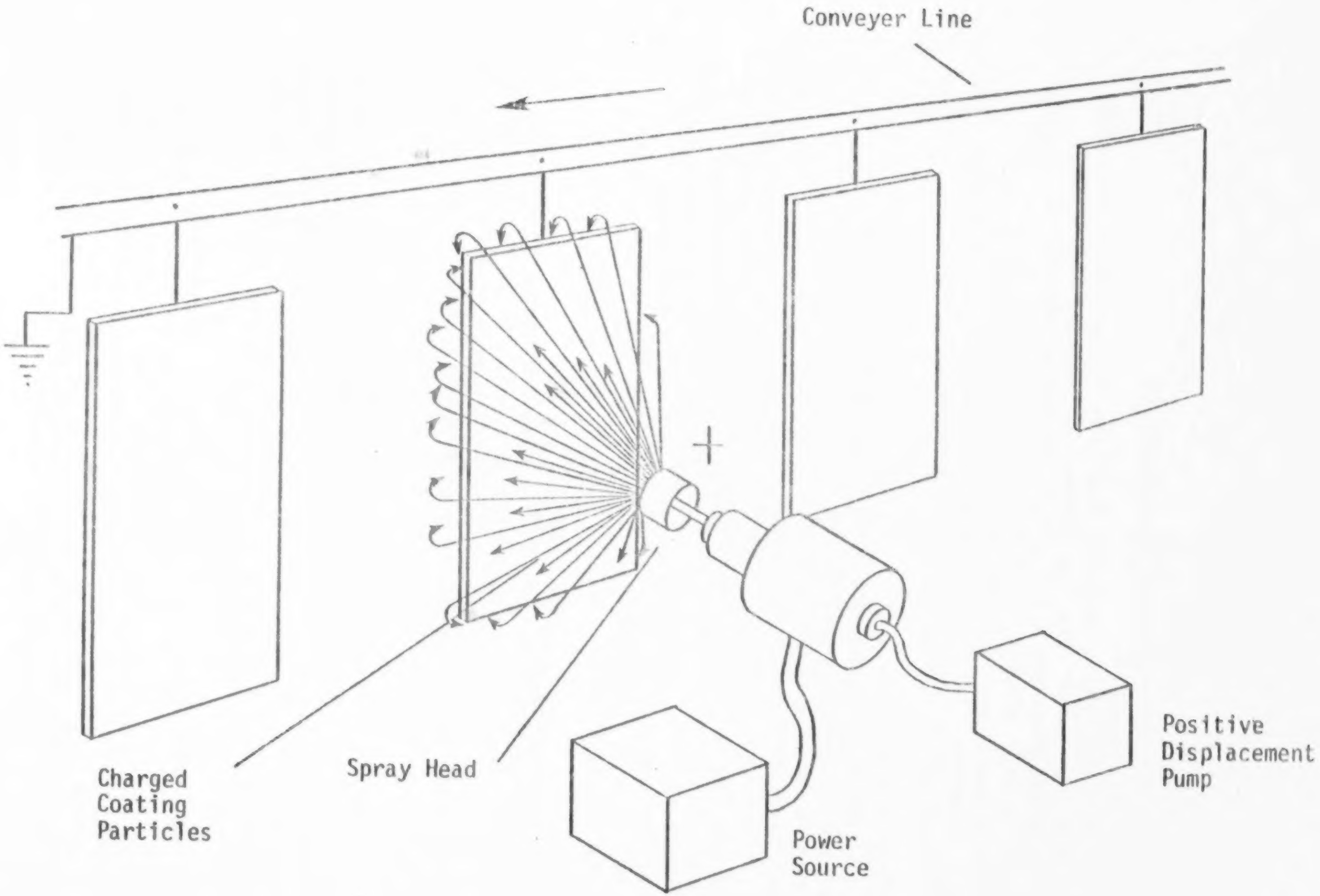
Conveyer Line
+
Charged
Coating
Particles
Spray Head
Power
Source
Positive
Displacement
Pump

Figure 3-1. Electrostatic spray operation.

For electrostatic spraying to be effective on wood furniture, the wood surface has to be made electrically conductive. This is done by applying a prepping solution (prep) to the wood before electrostatic spraying. The prepping solution is usually a salt solution diluted with textile or lactol spirits and can be applied by spraying, flowcoating, dipping or mixing with an existing coating. In addition, vendors recommend that electrostatic spraying be done at humidities greater than 40 percent to maintain the conductivity of the wood.[2] When the ambient humidity is too low, humidity chambers or room air humidifiers are used.

Humidity chambers (if used) are placed directly before the coating spray booth. Each piece that is to be sprayed electrostatically passes through the humidity chamber and is subjected to a relative humidity of 80-90 percent.[2]

Three basic types of spray heads are available. These are automatic disks, bells and manually operated handguns. If it can be used, most plants prefer automatic over manual spray equipment. One advantage is that because of better atomization techniques, more consistent spray control, and the elimination of human error, the automatic spray equipment can get better transfer efficiency. Another advantage of the automatic equipment is that there are lower labor requirements because usually one man can operate the control panel and monitor spraying for one or more spray booths.

The major advantages in converting to electrostatic spray equipment are the savings in the amount of coating sprayed which results in lower VOC emissions. According to one vendor, automatic spray equipment can achieve an 80 to 93 percent transfer efficiency under actual plant conditions while manual spray equipment can achieve around a 65 percent transfer efficiency.[3,4] The actual transfer efficiency for both types of equipment will depend on the system maintenance and the type of piece being sprayed. In addition, the performance of manual spray equipment will be affected by the operator's spray techniques. Depending on the efficiency of the conventional spray equipment, the improved transfer efficiency could result in a coating savings and VOC emissions reduction of anywhere from 30 to 75 percent.

Automatic electrostatic spray equipment is usually used on clear coats such as sealers and lacquers. Most plants prefer spraying color coats with manual spray equipment because the varying colors of grain require human judgement to produce a consistent color. Electrostatic spray equipment has been demonstrated to be effective on tubular or slender parts of furniture such as table legs, picture frames, chairs, and baby cribs. However, the large material savings experienced with spraying these pieces has not been demonstrated for larger pieces of furniture (case goods) for a number of reasons.

One of the major problems with electrostatic spraying of case goods is being able to apply the prep solution efficiently. Dipping or flowcoating are difficult due to the size and shape of the pieces. Hand spraying is difficult because the prep is clear which makes it hard to be sure that all parts of the case goods that are to be coated are sensitized. The best prep application would be to mix the prep in with a stain. With this method only parts of the case goods that are to be coated would also be sensitized. However, for certain types of stains, this method has not worked effectively. Currently, vendors are working to improve this process so that more facilities can use it.[5]

There is also a problem in the electrostatic spraying of case goods in finding an effective way to ground the piece of furniture. In most cases, the piece is grounded directly on the floor conveyer. In either case, some of the solvent sprayed is attracted to the grounded conveyer or stand which lowers the coating transfer efficiency. The case good also has to be able to be turned without losing its ground so that all the necessary parts can be sprayed. This has caused some difficulties in some installations. These difficulties do not occur with small pieces that can be hung from an overhead conveyer.

Another disadvantage with spraying case goods electrostatically is that because of their large size and varying sizes, automatic spray equipment is usually not applicable. Therefore, manual spray equipment is needed. With manual spray equipment, the transfer efficiency and thus the coating savings and VOC emissions reduction are not as high as with automatic equipment and may not justify the conversion.

Other factors have to be considered and accounted for in all electrostatic conversions. One is that the solvent content of the coating may have to be changed to allow the electrostatic equipment to work effectively. The solvent in the coating may need to be made "wetter" or less volatile and/or less conductive to optimize electrostatic spraying. In the cases of being made "wetter", a higher boiling point solvent is added or substituted to prevent the coating from drying out before it reaches the piece. In some cases, these higher boiling point solvents evaporate so slow that ovens are needed after the spray booth to dry the applied finish. In addition, these slower boiling point solvents may raise the price of the coating slightly. If the solvent is too conductive the spray head will lose its charge. A solvent with more resistivity will prevent the voltage leak and allow the atomized coating particles to maintain a high charge.

Another problem that may occur in some electrostatic conversions is that the expected emissions reduction may be reduced significantly when a separate prep application step is needed. Separate prep application steps, such as wiping, dipping, or flowcoating, require that the concentrated prep be diluted to four percent with organic solvents such as textile or lactol spirits. The evaporation of these solvents results in an additional VOC emissions source in the finishing operation. When the prep is mixed with an existing coating, these additional emissions do not occur.

3.1.2 Application of Electrostatic Spraying at Kabinart

Kabinart plans to install automatic electrostatic equipment on the door line sealer and lacquer spray booths and investigate the use of manual electrostatic spray equipment on all the remaining spray booths (both finishing line stain booths and the cabinet line sealer and lacquer booths). As mentioned earlier in Section 3.1.1, automatic electrostatic spraying of large pieces of furniture (case goods) is difficult because of difficulties encountered in the application. In addition, automatic electrostatic equipment does not work effectively on color coats such as stains because of the human judgement required to get an even color. This document will only investigate the automatic electrostatic spray conversions on the door line sealer and lacquer spray booths because of their greater potential for a reduction in the amount of coating required and thus a reduction in VOC emissions. It is felt that the manual conversions that Kabinart plans to investigate may not provide a large enough coating savings nor emission reduction to justify the conversion from a cost-effectiveness standpoint (dollars/ton of emission reduction).

The conversion to automatic electrostatic spraying on the door line would not be difficult. There is available space for the additional equipment required. Kabinart has done some preliminary tests of electrostatic spray equipment and has determined that automatic bells would be the best type. Some alterations to the door line would be required such as adding humidity chambers before each converted spray booth, altering the overhead conveyer and applying drying ovens after each spray booth. The door hangers would have to be altered so that instead of swinging freely the doors would maintain the proper position relative to the spray bells. In addition, the conveyer would have to be modified so that the doors would turn 180° after one side had been coated so that the other side could be coated. The drying ovens are needed because the lower volatility solvents used in the electrostatically sprayed coating will not evaporate fast enough.

Kabinart will apply the prepping solution by mixing the concentrated prep in with the stain in the stain spray booth because testing has shown this method provides the best finish quality. However, if this method cannot be used, then a separate prep application step would be required which could result in an additional VOC emissions source.

3.2 WATERBORNE COATINGS

Kabinart has also investigated using waterborne coatings in their coating process as a means of VOC control. A waterborne conversion of all the coatings was not considered because of the additional problems associated with a multi-step conversion. Because the stain is the largest emissions source, Kabinart selected a conversion to waterborne stain for further testing and study with a coating supplier.

3.2.1 Description of Waterborne Coatings

Waterborne stains have been available for a number of years. In the last five years, manufacturers have also developed other waterborne coatings, such as sealers and lacquers. A conversion from conventional, organic solvent-based coatings to waterborne coatings lowers VOC emissions because of the lower organic solvent content of the waterborne coatings. The organic solvent content of waterborne coatings is generally around 10 to 20 volume percent, while the majority of conventional coatings have organic solvent contents of 75 volume percent or more.[6,7] Other advantages to using waterborne coatings are that they are less flammable and can decrease dependence on petroleum products, lower worker exposure to toxic materials, and lower booth air flow requirements.

There are also some potential problems associated with the use of waterborne coatings. These problems can either affect the coating process or the finish quality. Some of the problems that have occurred in previous tests and demonstrations of waterborne coatings on wood furniture are listed below:

- grain raising
- increased drying time
- humidity control
- print resistance of topcoats
- changes in application techniques
- finish with lower gloss
- matching waterborne finishes with existing finishes
- repairability of the finish

Each of the problems presented are further discussed below.

Grain raising is one of the major problems affecting the performance of waterborne coatings. It occurs because the wood fibers absorb the water solvent causing the wood to swell. Additional labor is then required to sand the wood surface so that a smooth final finish can be obtained. When grain raising occurs on pieces with irregular shapes or intricate designs, it is difficult to get a smooth overall surface. Grain raising can be minimized if the wood surface has already been sealed. However after sealing, the wood cannot be easily stained, colored, and highlighted.

Generally, additional drying is needed with waterborne coatings because water evaporates slower than organic solvents. Increased drying time can be provided by increasing the distance between spray booths or slowing down the conveyer line. Alternatively additional drying capacity can be provided by raising oven temperatures. High humidity conditions will increase the need for additional drying times.

For waterborne conversions where many coating steps are converted, some type of humidity control may be needed to handle the water vapor that evaporates from the applied coatings. The excessive moisture could slow down drying and affect the quality of the finish due to problems such as softness of the finish. The amount of excess moisture increases with the number of coating steps that are converted.

Waterborne topcoats may have less resistance to printing than the organic solvent-based topcoats. Wood furniture needs to have a strong, print resistant finish because most of it is boxed and stacked immediately after finishing. In previous tests it has been found that the print resistance of waterborne topcoats improves with age.[8] Even though the finish is dry to the touch, it generally requires extra time to set. Therefore, extra storage space may be required.

Because waterborne coatings differ in formulation from conventional coatings, the working and application characteristics are usually different. Therefore new application, rubbing, and wiping techniques may be required.

Finish quality may also be different with waterborne coatings. In tests done by furniture manufacturers, waterborne finishes did not have the same gloss as conventional finishes.[9] In addition, it could be difficult to match the waterborne finished pieces to those with conventional finishes. This would cause problems for consumers who have bought parts of a suite of furniture and want to match the new waterborne finished furniture with the old, conventional finished furniture.

Another problem occurs in the repairability of the waterborne coatings. On the manufacturing level 10 to 25 percent of all furniture must be repaired. Also retailers must do spot repairs. With waterborne coatings intermediate color changes, highlighting, or shade matching is difficult. In addition when dry, waterborne coatings are harder to remove than conventional coatings. Little work has been done in developing waterborne finish repair procedures. For waterborne coatings to be acceptable, additional repair techniques will have to be devised.

Many of the problems presented above will affect fine furniture producers much more than the lower quality producers. In addition, low quality furniture requires fewer finishing steps than high quality furniture so fewer steps will have to be converted to achieve a significant emissions reduction. The number of problems that occur should decrease with fewer coating steps converted.

The major cost associated with waterborne conversions is replacing the storage, distribution, and spraying system with corrosion resistant equipment. In addition any of the equipment that is outside will have to be heated and insulated or moved inside to protect the coatings from freezing.

Some furniture manufacturers are using waterborne coats for one or more coating steps effectively and are meeting finish quality requirements.[10] These conversions are generally on a case by case basis for a specific finish or product. Coating suppliers are working with furniture manufacturers to try and improve waterborne coatings and limit the number of problems that exist.

Because of the problems associated with a multi-step conversion, a total waterborne finish system has not been demonstrated to produce an acceptable finish in the commercial wood furniture industry. There is a total waterborne finish system at the Enterprise Workshop at Virginia State Penitentiary which produces state institutional office furniture. This facility applies one stain, two sealer coats, and one lacquer to pieces such as desks, couches, chairs, conference tables, and bookcases. They report a finished product that is improved in quality and appearance over their conventional coatings. However, this plant is at an advantage because it does not have to meet as tight a production schedule as private plants would.[11]

If waterborne coatings are planned to be used for a certain application, it will be necessary to test them on the specific product line under actual operating conditions. The tests will help determine whether any of the problems presented earlier exist and may also help identify any other problems not previously considered. Some of the solutions to these problems may be simple; however, some may require extensive changes in the finishing schedule to achieve an acceptable finish. It will be important in most waterborne conversions that the final finish meet the plant's specific finish quality requirements.

3.2.2 Application of Waterborne Stains at Kabinart

Kabinart has conducted an investigation into the feasibility of a conversion to waterborne coatings. They selected a waterborne stain for testing because its conversion had the largest potential VOC emissions reduction. A single coating conversion was selected because generally the number of problems decreases with a decrease in the number of coating steps converted.

The waterborne stains investigated by Kabinart have a VOC content of about 5 percent. The present conventional stains have VOC contents of about 99 percent.[12] The conversion to a waterborne stain could then result in about a 95 percent reduction in VOC emissions from the staining operation.

The potential problems associated with a waterborne coating conversion were discussed earlier in Section 3.2.1. During testing of the waterborne stains at Kabinart, some of these problems were experienced. They are outlined below.

- Significant grain raising occurred. When sanding, the operator had to sand so much to make the surface smooth that some of the stain was removed.
- Kabinart could not maintain a consistent color during the tests.
- Kabinart could not achieve the colors that they wanted.
- The waterborne stain finish had a poor clarity and color when compared to the conventional stain finish.

Because of these problems, Kabinart discontinued the testing of the waterborne stains. With continuing study of waterborne coatings in the furniture industry some of the problems with waterborne stains may be reduced or eliminated. Therefore, waterborne stains will be included in this study of reasonably available control technology (RACT) because of their potential use at a later date. It is also possible that at a later date waterborne sealers or topcoats could also be applied at Kabinart but this also will require extensive testing.

There are also potential problems with having both the waterborne stains and the electrostatic equipment on the door finishing line. The type of changes required will depend on the prep application method. If the prep is mixed with the waterborne stains there will have to be some testing done to determine if the prep affects the stain's performance. If a dip tank is used to apply the prep then the dip tank will probably have to be placed after the stain booth and oven.

3.3 INCINERATION

Incineration was also investigated as a potential VOC control at Kabinart. Incineration is technologically feasible for the control of VOC emissions from furniture coating operations; however, it has not been demonstrated in the wood furniture industry because of the high control costs.

Two types of incinerators are available, thermal and catalytic. Thermal incineration involves the oxidation of organic vapors to carbon dioxide and water. The solvent laden air is exposed to a high temperature of 540° to 820°C (1000 to 1500°F) and in some cases a direct flame for a period of 0.3 to 0.6 seconds. Catalytic incinerators use a catalyst bed to oxidize the organic vapors and operate at reduced temperatures of 400° to 540°C (750°-1000°F). Important incineration operating factors are residence time, operating temperature, type and concentration of organics in the gas stream, and the gas stream flow rate.

When collected, most waste gases have very low heat contents. This is due in part to insurance regulations which limit the maximum concentration of organics to 25 percent of the lower explosive limit (LEL) when no LEL meter is used. If an LEL meter is present to constantly monitor the gas stream, then the organic concentration can be as high as 40 percent of LEL. In either case, supplemental fuel is needed to raise the off gases to the required operating temperature.

Heat recovery equipment is also used with incinerators to reduce the amount of supplemental fuel required. It is generally divided into primary and secondary recovery. Primary heat recovery uses heat exchangers to recover heat from the incinerator exhaust gases to heat the incoming air. Secondary heat recovery recovers heat from the exhaust gases for use in plant processes such as ovens, dryers, etc.

The destruction efficiency of both thermal and catalytic incinerators depends on the operating and design factors. In general these devices can achieve between 90 and 99+ percent destruction.

Incinerators have not been demonstrated as VOC control devices in the furniture industry because of several problems. The main problem results from the high spray booth exhaust air flows and low VOC concentrations. Air flows can range from 140 to 1,400 m^3/min (5,000-50,000 scfm) while VOC concentrations are usually less than 200 ppm. These conditions would result in the exhaust stream having a low heat content thus resulting in high supplemental fuel requirements. Another problem results from the fact that the exhaust streams from the different spray booths cannot be ducted together because of fire hazards. One fire hazard results from the nitrocellulose solids present in the coatings settling out in the ducts. A build up of nitrocellulose in the ducts could cause an explosion or fire. Another fire hazard could result from the mixing of different solvents and coatings from several spray booths. Certain solvents and coatings cannot be mixed together because they may spontaneously combust. Since the exhausts from the spray booths cannot be ducted together each spray booth would require its own incinerator.

3.4 CONCLUSIONS

All the controls described in this chapter would be technologically feasible at Kabinart. However, electrostatic spraying seems to be the best choice for a RACT determination. The application of waterborne coatings is highly site specific and currently waterborne stains are not feasible at Kabinart because of problems with the finish appearance. However, they could potentially be used at a later date if some of the difficulties are reduced or eliminated. Both of these controls will be investigated in Chapters 4 and 5 for their environmental impacts and control costs. Incineration will not be considered further because a preliminary investigation has shown it to be too expensive ($6,200 - 9,500/ton VOC removed).[14]

3.5 REFERENCES

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4.0 ENVIRONMENTAL IMPACTS

Chapter 4 discusses the environmental impacts associated with applying the two control alternatives to the coating operation at Kabinart Corporation. The two controls evaluated are electrostatic spraying and waterborne stains. The air pollution, water pollution, solid waste, and energy impacts associated with each control are discussed in Sections 4.1 to 4.4, respectively.

4.1 AIR POLLUTION

The impact of each control alternative on air quality is presented in this section. Two impacts are considered. One is the primary impact or the reduction in VOC emissions due to the application of the control options. The second is the secondary impact or the pollutants generated as a result of applying the control equipment.

4.1.1 Electrostatic Spraying

As presented in Chapter 3, applying electrostatic spray equipment can lower coating requirements and reduce VOC emissions from 30 to 75 percent from the coating operation. The emissions reduction will depend on the original spray application technique, the type of electrostatic equipment used, and the type of furniture being coated. At Kabinart, the electrostatic spray equipment will be applied on the door line sealer and lacquer spray operations. In evaluating the environmental impacts of electrostatic spray, a 40 percent coating savings or emissions reduction is used. This value was chosen based on the range presented above and conversations with electrostatic equipment vendors. In addition a 25 percent coating savings or emissions reduction is presented because this amount was guaranteed by the vendor for the application at Kabinart. Both of these coating savings assumptions are on the low end of the range of values reported above (30 to 75 percent).

As mentioned earlier, Kabinart will apply the prep by mixing it with the stain. However, if difficulties are encountered in using this method at a later date, then another prep application method will have to be used. The alternative used most often in other conversions is a dip tank. However, if a dip tank is used then another emissions source is created. The emissions result from the evaporation of the solvents used to dilute the prep. Table 4-1 presents the VOC emissions from each converted coating operation before and after applying electrostatic spray equipment. These emissions are presented for the cases where the prep is mixed with the stain and where a dip tank is used.

As seen from Table 4-1, applying electrostatic equipment to the door line sealer and lacquer booths can reduce total plant VOC emissions by

TABLE 4-1. VOC EMISSIONS WITH ELECTROSTATIC SPRAY EQUIPMENT AT KABINART CORPORATION[a]

Finishing Step	Uncontrolled Emissions		Controlled Emisssions							
			40 Percent Emissions Reduction				25 Percent Emissions Reduction			
			(no dip tank)		(with dip tank)		(no dip tank)		(with dip tank)	
	Mg/yr	(tons/year[b])	Mg/yr	(tons/year[b])	Mg/yr	(tons/year[b])	Mg/yr	(tons/year[b])	Mg/yr	(tons/year[b])
Sealer-Door Line	17	(19)	10	(11)	10	(11)	13	(14)	13	(14)
Lacquer-Door Line	15	(16)	9	(10)	9	(10)	11	(12)	11	(12)
Prep Application-Dipping	-	-	-	-	6	(7)	-	-	6	(7)
	32	(35)	19	(21)	25	(28)	24	(26)	30	(33)
% Reduction over total coating process (plant) emissions			9		5		6		1	

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[a] Assume a 40 or 25 percent coating savings from each converted coating step. This results in a 40 or 25 percent emissions reduction.

[b] Facility operates 2,000 hours/year so VOC emissions in lbs/hr equal emissions in tons/year.

9 percent or 13 Mg/yr (14 tons/year) with a 40 percent coating savings and by 5 percent or 8 Mg/yr (9 tons/yr) with a 25 percent coating savings. If a dip tank is used the emissions reduction is lowered significantly.

The expected increase in secondary emissions due to the conversion to electrostatic spraying will be too small for consideration.

4.1.2 Waterborne Stains

A conversion to waterborne stains at Kabinart can reduce the organic solvent content of the applied stains from 99 percent to 5 percent. Assuming that the same amount of stain is applied after the conversion then VOC emissions can be reduced by 95 percent from the staining operations on both the door and cabinet finishing lines. Table 4-2 presents the VOC emissions before and after the waterborne stain conversion. In addition the effect of this emissions reduction on the overall coating process emissions is presented.

As seen from Table 4-2, the waterborne stain conversion can lower VOC emissions by 56 Mg/yr (62 tons/year). This is a 40 percent reduction in the overall coating process VOC emissions at Kabinart.

There is no secondary air pollution impact with the conversion to waterborne stains.

TABLE 4-2. VOC EMISSIONS WITH WATERBORNE STAINS AT KABINART CORPORATION

Stain Operation	Uncontrolled Emissions[a] Mg/yr	Uncontrolled Emissions[a] (tons/year[b])	Controlled Emissions[a] Mg/yr	Controlled Emissions[a] (tons/year)
Cabinet Line	35	(39)	1.8	(2)
Door Line	24	(26)	0.9	(1)
	59	(65)	2.7	(3)
% Reduction over total coating process (plant) emissions				40

[a] Conventional stains have a VOC content of 99 percent while waterborne stains have a VOC content of 5 percent.

[b] Facility operates 2,000 hours/year so emissions in lbs/hr equal emissions in tons/year.

4.2 WATER POLLUTION

There is no water pollution impact with the application of either of these controls at Kabinart Corporation.

4.3 SOLID WASTE POLLUTION

There is no solid waste impact due to the application of these controls at Kabinart Corporation.

4.4 ENERGY IMPACTS

There is an increase in the electricity requirements for electrostatic spraying because of the power needed to charge the coating particles and to operate the drying ovens. The power source to charge the coating particles requires about 7.2 GJ/yr (2000 kWh/yr). The oven after the sealer booth requires 72 GJ/yr (20,000 kWh/yr) while the oven after the lacquer booth requires 108 GJ/yr (30,000 kWh/yr). The added electricity requirements amount to about 187 GJ/yr (52,000 kWh/yr) which is less than 14 percent of the electricity used by Kabinart in 1 year. For waterborne stains, there is no added electricity requirements.

4.5 REFERENCES

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5.0 EMISSION CONTROL COST ANALYSIS

Chapter 5 presents the control costs for the conversion to electrostatic spraying and waterborne stains on the coating process at Kabinart Corporation. Sections 5.1 and 5.2 present the bases for the capital and annualized costs, respectively. Section 5.3 presents and compares the annualized costs for the two controls and Section 5.4 presents the cost effectiveness for each of the controls. All costs presented are based on second quarter 1981 dollars and were updated using the M&S equipment cost index.[1]

5.1 BASIS FOR CAPITAL COSTS

Capital cost is the total investment required for purchase and installation of a complete pollution control system. Components of capital cost include the cost of equipment, all material and labor for installation, and other associated indirect costs. The indirect costs include items such as engineering and construction expense and construction fees. Also included in the capital cost is an allowance for contingencies. The capital cost bases for the application of electrostatic spraying and waterborne stains at Kabinart are presented in the following sections.

5.1.1 Electrostatic Spraying

As mentioned in Chapter 3, the most efficient electrostatic spray application at Kabinart is the use of automatic equipment on the door line sealer and lacquer spray operations. The equipment required for the conversion at each spray booth is presented in Table 5-1. This equipment can be installed during a scheduled plant shutdown. For this conversion, each spray booth has four automatic spray bells situated next to each other in a row facing the overhead conveyer. All four bells are connected to a reciprocating arm that moves them up and down about 12 inches to produce an even coat. The first two bells spray one side of the cabinet door while the last two bells spray the other side. The overhead conveyer has to be altered so that the doors will turn 180° after the first two bells. In addition, the doors hangers have to be altered so the doors maintain the proper position relative to the bells. The sealer operation will require a 10,000 watt (34,100 Btu/hr) and the lacquer operation a 15,000 watt (51,200 Btu/hr) drying oven to evaporate the low volatility solvents remaining in the applied coatings.

Two prepping solution applications were also investigated. The method preferred by Kabinart because it gave the best finish quality in preliminary tests is mixing the prepping solution in with the existing stain. No additional equipment is required for this operation. If this method cannot be used then a separate prep application step will have to be added. In most demonstrated electrostatic spray conversions, a dipping operation is used;

TABLE 5-1. EQUIPMENT INCLUDED FOR THE ELECTROSTATIC SPRAY CONVERSION

Equipment Required at Each Converted Spray Booth[a]

- 4 - Reciprocating automatic spray bells
- 1 - Humidity chamber
- 1 - Power source
- 1 - Positive displacement pump
- 1 - Control panel
- 1 - Safety device ("Crowbar") that will ground out the system in case of a spark
- 1 - Drying oven after each spray booth. The sealer spray booth will require a 10,000 watt oven and the lacquer spray booth will require a 15,000 watt oven

Equipment Required to Apply the Prepping Solution

a. If the prep is mixed in with the stains, no additional equipment required.

b. If the doors are dipped

Equipment required:

- Sheet metal dip tank - 3' wide x 5' long x 4' deep
- Ducting
- Pump and pipe for fluid recirculation
- Exhaust fan
- Collection hood

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[a] More exact specifications for this equipment were not required to determine the costs because the total equipment cost was provided by the plant.

therefore, this method was selected as an alternative for Kabinart. The equipment needed for a dipping operation is also presented in Table 5-1.

The total capital investment for the electrostatic conversion assuming that the prep can be mixed with the stain was provided by the plant.[2] This cost estimate includes direct and indirect investment costs and contingencies. For the case where the prep solution is applied by dipping the doors, separate capital costs were developed and added to the capital cost for the electrostatic system provided by the plant. The equipment costs for the dipping operation were obtained from cost estimating manuals and vendors.[3,4] The installation costs and indirect investment costs were estimated to be 50 percent and 30 percent respectively of the purchased equipment costs for the dipping operation.[5]

5.1.2 Waterborne Stains

Kabinart selected a waterborne stain for investigation because it has the potential for the largest VOC emissions reduction. Since Kabinart applies four basic colors of stain, they will use four waterborne stains also. The delivery and spray equipment for the waterborne stains is the same design as for the conventional equipment; however, the waterborne stain equipment is made of stainless steel to protect from corrosion. All of the stain lines are similar to each other. Each line is a circulating system that transports the stain to the cabinet and door line stain spray booths. The equipment required for each stain line is presented in Table 5-2. This equipment can be installed during a scheduled plant shutdown.

Equipment and installation costs including materials, labor, and any indirect costs were provided by a vendor.[6-9] In addition, a contingency of 20 percent was added to these costs.

TABLE 5-2. EQUIPMENT NEEDED FOR THE WATERBORNE STAIN CONVERSION
(per stain line)

550 ft. 304 stainless steel pipe, ½ in. schedule 40
Pump, agitator system 5:1 Ratio 2.5 gpm
Mixing room equipment (valves, guages, connections)
Back pressure valves (3)
Fluid Regulator (4)
Air Atomized Spray Guns (4)
Fluid Hose 25 ft. 3/8 in. nylon-lined (4)

5.2 BASIS FOR ANNUALIZED COSTS

Annualized costs represent the yearly cost of operating and maintaining the control equipment and the cost of recovering the initial capital investment. The annualized costs bases for the application of electrostatic spraying and waterborne stains at Kabinart are presented in the following sections. All of these costs are based on 2,000 hr/yr of operation.

5.2.1 Electrostatic Spraying

The basis for the annualized cost estimates are presented in Table 5-3. Two of the major operating costs are the additional costs for the electrostatic coating and the prepping solution. The electrostatically sprayed sealer and lacquer will have to be reformulated with slower evaporating solvents. The plant estimates that these new formulations will raise the price of these coatings by $1.15/gallon.[11] This estimate seems high when compared to other electrostatic conversions. According to vendors the prep costs between $15 and $20/gallon so $20/gallon was selected for these cost estimates.[12] When the prepping solution is mixed with the existing stain, the prep is applied at a concentration of 4 percent. If a dipping operation has to be used then it is assumed that 67 percent less prep will be used in the dipping operation than when mixing the prep with the stain.[13] The reason is that the dipping operation applies the prep more efficiently. However, an added operating cost results in dipping because textile or lactol spirits have to be used to dilute the prep to 4 percent. The cost of these solvents is about $2.00/gal.[2] It is also assumed that no additional maintenance for the electrostatic equipment over that of the existing conventional equipment is required.

The major benefit of applying electrostatic equipment is the reduction in the amount of coating that has to be sprayed to coat the piece. As stated in Chapter 4, a 40 and 25 percent coating savings will be investigated for this conversion. Another benefit resulting from the application of electrostatic equipment is lower spray booth air flow requirements and a reduction of make-up air requirements. However, this savings is offset by the costs of the additional exhaust capacity needed for the finishing room. This additional capacity is needed because the slower evaporating solvents in the electrostatic coatings will cause more VOC evaporation into the finishing room and less in the spray booths.

In addition, because of the use of the automatic spray equipment, Kabinart may be able to reduce the number of workers required at each converted spray booth thereby reducing labor costs. The automatic electrostatic spray conversion may also allow Kabinart to increase their production rate by placing the doors closer together on the finishing line. Even though these coatings may reduce costs significantly, they will not be included in this study because the amount of savings of each cannot be quantified except under actual production.

The capital charges are also presented in Table 5-3. These include the capital recovery factor, general administration, taxes and insurance.

5.2.2 Waterborne Stains

Table 5-3 also presents the annualized cost bases for the waterborne stain conversion. The major cost is the labor required to sand the wood

TABLE 5-3. ANNUALIZED COST BASES FOR ELECTROSTATIC SPRAYING AND WATERBORNE STAINS[a]

Direct Operating Costs	
Utilities	Electricity: $0.04/kWh.[10]
Operating Labor	Sanding labor: $6.25/hr. Includes fringe benefits.
Maintenance Labor	No additional labor required over that of the existing systems.
Additional Coating Costs	The new coating formulations will raise the cost of the sealer and lacquer from $5.50/gallon to $6.65/gallon.[13]
Prepping Solution Costs	Prepping solution costs $20/gallon and is diluted to 4 percent. If dipping is required textile or lactol spirits are used as solvent at $2.00/gallon.
Waterborne Stain Costs	Waterborne stains are expected to cost 10% more than the conventional stains. Conventional stains cost $4.50/gallon so additional cost of $0.45/gallon will result from the conversion.
Capital Charges	
Taxes and insurance	2 percent of capital cost
Administration and Permits	2 percent of capital cost
Capital Recovery Factor	16.1 percent of capital cost; 12 percent interest rate and 12 year equipment life.

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[a] Plant operates 2000 hr/yr.

surface if significant grain raising occurs. The plant is not sure how many sanders will be needed until actual production occurs. However, they estimate that 3 or 4 sanders will be needed. For this analysis, 3 additional sanders will be used. Each of these sanders will work full-time (2,000 hrs/year) at a labor rate of $6.25/hr.[13] The plant also estimates that the waterborne stains will cost 10 percent more than the conventional stains; therefore, it was assumed that the waterborne stains cost $4.95/gal.[14] There are no additional utility requirements or maintenance resulting from the waterborne stain conversion.

A benefit results from the conversion because the spray booth air flow can be reduced by 40 percent. The lower air flow are allowed because of the lower organic solvent content of the waterborne stains.

The same capital recovery factor that is used for the electrostatic spraying annualized costs is used for waterborne stains.

5.3 EMISSION CONTROL COSTS

Tables 5-4 and 5-5 present the control costs for the conversions to electrostatic spraying and waterborne stains, respectively at Kabinart. For electrostatic spraying, the costs for a 40 and 25 percent coating savings for the two prep application alternatives are presented. Both the amount of material savings and the type of prep application have a significant effect on the conversion costs. The dipping operation is more expensive than mixing the prep with the stain because of the extra solvent required to dilute the prep to 4 percent and the extra equipment needed. If the prep can be mixed with the stain and a 40 percent coating savings can be achieved, a control cost of $11,700/year will occur.

As mentioned earlier, the information needed to arrive at these costs was provided by Kabinart. The costs presented are specific to Kabinart and are felt to be conservative estimates that are on the high end of the range when compared to other electrostatic conversions in the industry. The higher costs at Kabinart are caused primarily by three factors; the considerably higher cost of the electrostatic coatings used, the low coating savings assumed, and the need for additional drying ovens. Kabinart estimates that the electrostatic sealer and lacquer will cost 21 percent higher than the present coatings because of the special lower volatility solvents needed. This is considerably more expensive than what has been reported to be used in previous electrostatic conversions. Also, the 25 and 40 percent coating saving values used in this analysis are on the low end of the range of coating savings reported in other conversions. It is possible that Kabinart could achieve at least 40 percent and possibly higher coating saving when production begins. The third factor, additional drying ovens, is not always required in electrostatic spray conversions because of sufficient drying time or drying ovens that are already present.

In addition, Kabinart should be able to lower their electrostatic conversion costs significantly because they should be able to achieve an increased production rate and lower labor requirements at the two converted spray booths. These conditions were not included in the control costs

Table 5-4. CONTROL COSTS FOR ELECTROSTATIC SPRAYING
(2nd Quarter 1981 Dollars)

Electrostatic Spray Alternative		Annualized Costs			
	Capital Costs	Direct Operating Expense	Capital Charges	Savings[a]	Net Annualized Costs
40% Coating Savings					
If prep mixed with stain	$110,900	$ 8,400	$22,300	$19,000	$11,700
If dip tank is used	118,000	9,400	23,700	19,000	14,100
25% Coating Savings					
If prep mixed with stain	110,900	8,400	22,300	6,400	24,300
If dip tank is used	118,100	9,400	23,700	6,400	26,700

[a] A savings in operating expenses results from the conversion because of the coating savings and lower spray booth airflow requirements.

TABLE 5-5. CONTROL COSTS FOR THE WATERBORNE STAIN CONVERSION
(2nd Quarter 1981 Dollars)

		Annualized Costs			
	Capital Costs	Direct Operating Expense	Capital Charges	Savings[a]	Net Annualized Costs
(Sanding Labor)					
3 men	$35,600	$46,000	$7,160	$1,160	$52,000

[a] A savings in operating expenses results from the conversion because of lower spray booth airflow requirements.

because the amount of each would have to be determined during actual production.

It is felt that when accounting for an increased production rate and lower labor requirements the actual costs of the electrostatic spray conversion will be considerably lower than what is reported above. In addition if Kabinart can reduce the costs of their electrostatic coatings and achieve better than a 25 percent coating savings it is possible that an overall cost savings may result.

For the waterborne stain conversion, the major factor affecting the conversion costs is the amount of labor required to sand the wood surface if grain raising occurs. The annualized costs are presented for the case where 3 sanders are needed. The annual costs for this control are $52,000/year.

5.4 COST EFFECTIVENESS

Table 5-6 presents the cost effectiveness for electrostatic spraying and waterborne stains. In addition, the annualized costs and emission reduction for each alternative are presented. The cost effectiveness of electrostatic spraying when the prep is mixed with the stain ranges from a cost of $840/ton of emissions reduction to a cost of $2,700/ton of emissions reduction depending upon the amount of coating savings achieved. Application of waterborne stains will result in a cost effectiveness of 840/ton of emissions reduction assuming that 3 sanders are needed.

TABLE 5-6. COST EFFECTIVENESS FOR ELECTROSTATIC SPRAYING AND THE WATERBORNE STAIN CONVERSION

Control	Annualized Cost	Emissions Reduction tons/year	Cost Effectiveness $/ton VOC reduced
Electrostatic Spraying			
40% Material savings			
Prep mixed with stain	$11,700	14	840
Dipping	14,100	7	2,000
25% Material savings			
Prep mixed with stain	24,300	9	2,700
Dipping	26,700	2	13,400
Waterborne Stain			
number of sanders			
3	52,000	62	840

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SECTION C

FIBERGLASS BOAT MANUFACTURING

1.0 INTRODUCTION AND SUMMARY

1.1 PURPOSE OF DOCUMENT

The purpose of this document is to present the findings of an investigation of Reasonably Available Control Technologies (RACT) for the fiberglass boat manufacturing process at Hydra-Sports, Inc. in Nashville, Tennessee. This facility was selected by EPA Region IV and the Nashville Metropolitan Health Department because it has the potential to emit more than 90 Mg (100 tons) of VOC yearly. The RACT investigation is based on existing or readily available information obtained from emissions inventories, permit files, and technical journals. In addition, Radian visited Hydra-Sports and the Nashville Metropolitan Health Department to obtain first hand information.

Chapter 2 of this document consists of a discussion of the VOC emissions sources and the factors affecting VOC emissions. Chapter 3 describes the potential emission controls for the emissions sources along with a discussion of their applicability. Chapter 4 and 5 present the environmental impacts and a cost analysis for the controls being considered as potential candidates for RACT. The technical information provided will serve as a basis for regulatory action.

1.2 SUMMARY

Hydra-Sports, Inc. in Nashville, Tennessee manufactures 4 to 7 m (14 to 24 ft) lightweight fiberglass boats. The manufacturing process generates two types of VOC emissions, styrene emissions from the application of the polyester resin and acetone emissions from cleanup of worker's hands and tools. Disposal of spent acetone offsite is an additional source of acetone emissions in the Nashville area. Four controls were considered for controlling VOC emissions from Hydra-Sports. These were chemical scrubbers and incinerators for the spray booth exhausts, process changes specifically to reduce styrene emissions, and work practice controls specifically to reduce acetone emissions. In addition, acetone recycling was considered for control of VOC emissions from acetone disposal off-site.

Preliminary investigation showed that both chemical scrubbing and incineration were too expensive for this application. One of the process changes considered to control styrene emissions, suppressed styrene resins, has not been demonstrated to produce an acceptable product for some applications.

The controls selected for potential RACT were low styrene resins, acetone work practice modifications, and commercial recycling of spent acetone. The environmental impacts and costs ~~of~~ these controls are presented in Chapters 4 and 5, respectively.

Low styrene resins would reduce styrene emissions by 1.2 Mg/yr (1.3 tons/yr) or 2.5 percent of total plant VOC emissions at no additional cost. For molding room emissions, work practice modifications could reduce VOC emissions by 7.9 Mg (8.8 tons) per year which is a 17 percent reduction in total plant VOC emissions. The cost of this control ranges from a cost of $3800 per year to a savings of $22,000 per year depending upon the amount of acetone issued and whether a cost credit for reduced acetone evaporative losses is included. The cost effectiveness ranges from a cost of $430/ton of emissions reduction to a savings of $140 to $2500/ton of emissions reduction .

Commercial recycling of the spent acetone would eliminate all of the 44.3 Mg/yr (48.9 tons/yr) of acetone emissions which occur at the waste disposal site. This control would result in a cost savings ranging from $930 to $4,000 per year. The cost effectiveness of recycling would be a savings of $77/ton of acetone recovered.

2.0 PROCESSES AND POLLUTANT EMISSIONS

This chapter describes the fiberglass reinforced plastic boatbuilding source category. Production of fiberglass boats is discussed along with the associated VOC emissions. The chapter is divided into three sections. Section 2.1 briefly describes the general industry and Section 2.2 describes the manufacturing process and its emissions. Section 2.3 discusses the manufacturing process and VOC emissions at Hydra-Sports.

2.1 INDUSTRY STRUCTURE

The fiberglass reinforced plastic boat industry is composed of many small businesses contained within SIC code 3732, Boat Building and Repairing. There is a wide range in the number of employees and the size of boats built. Only 210 fiberglass boat manufacturing facilities employ more than 50 people and the largest reported facility employs 900 people.[1] The size of fiberglass boats ranges from less than 3.7 m (12 ft) up to 70 m (230 ft) in length. Fiberglass boats are generally divided into two size categories. Boats 9 m (30 ft) in length or less are termed "small" and boats greater than 9 m (30 ft) in length are termed "large". A facility may produce as many as 70 boats per day or as few as one boat per week depending on the boat size.

Hydra-Sports Incorporated is a medium-sized fiberglass boat manufacturing facility which specializes in construction of small lightweight boats. They employ 96 people of which 18 are laminators. The facility produces an average of six boats per day ranging in length from 4 to 7 m (14 to 24 ft). The maximum capacity of the facility is about ten boats per day.

2.2 GENERAL INDUSTRY PRODUCTION PROCESS AND EMISSIONS

There are several production methods applicable to fiberglass boat manufacturing. However, the major method used in production of small boats is contact open molding.[2] The following discussion is limited to this method. The VOC emissions associated with the production process are styrene, acetone, and carpet glue solvent vapors.

2.2.1 Fiberglass Boat Production Process

The contact molding method consists of applying layers of resin impregnated fiberglass reinforcement (laminate) on an open female or male mold. The laminate is built up to the required thickness and then allowed to harden or cure. After the cure is completed, the part is removed and the mold is reused. A male mold is convex leaving a smooth inner surface and a female mold is concave leaving a smooth outer surface on the product. Since a smooth outer surface is normally desired,[3] female molds are most commonly used in fiberglass boat production.

The primary type of resin used in fiberglass boat production is polyester resin.[4] Polyester resins typically consist of 45 percent styrene monomer and 55 percent polyester solids.[5] Before applying the resin, the necessary catalyst and accelerator are added to initiate curing. During curing, the styrene monomer polymerizes forming a thermosetting plastic. This is an exothermic process, and because styrene monomer reacts more rapidly at elevated temperatures, the reaction is autocatalytic.[6]

The general production process steps used in the industry for manufacturing fiberglass boats are shown in Figure 2-1. The different parts of the boat (deck, hull, small parts) are fabricated in the molding room. The decks and hulls are fabricated in the main area of the molding room while the small parts are fabricated in the small parts booth. The first step in the production process is coating the mold with a releasing agent such as wax. A gel coat is then applied on the mold with a spray gun in a ventilated spray booth. The gel coat is a pigmented polyester resin which forms the outer smooth surface of the molded part. After spraying, the gel coat hardens or cures with a smooth surface against the mold and a tacky outer surface which enhances later bonding of the first layer of laminate.

After the gel coat cures, the first layer of resin and fiberglass laminate is applied using one of the lamination methods described below. The lamination procedure is repeated until the desired thickness is achieved. Structural reinforcements such as wood, plastic, and metal are also added during lamination. Lamination is a batch process with time between laminates dependent on cure time of the resin. After the final lamination has cured, the excess is trimmed from the part and the part is removed from the mold.

After the parts are removed from the mold, they are then taken to the assembly room where they are sanded and the boat is assembled. In addition, carpet and accessories are often installed to produce the finished product.

2.2.2 Methods of Lamination

There are two methods of lamination used in the fiberglass boat manufacturing industry. These are hand lay-up and spray-up. Each method offers advantages and disadvantages over the other and a combination of the two is often used.

In the hand lay-up method, resin is applied with a resin gun or in rare cases with a brush. If a resin gun is used to apply the resin, a brush is usually employed to even out the resin. After a thin coat of resin has been applied to the gel coat or previous layer of laminate, fiberglass reinforcement is placed over the wet resin. The primary fiberglass reinforcements used in hand lay-up are woven roving, cloth, and mat. Squeegies or metal rollers are then used to force the resin up

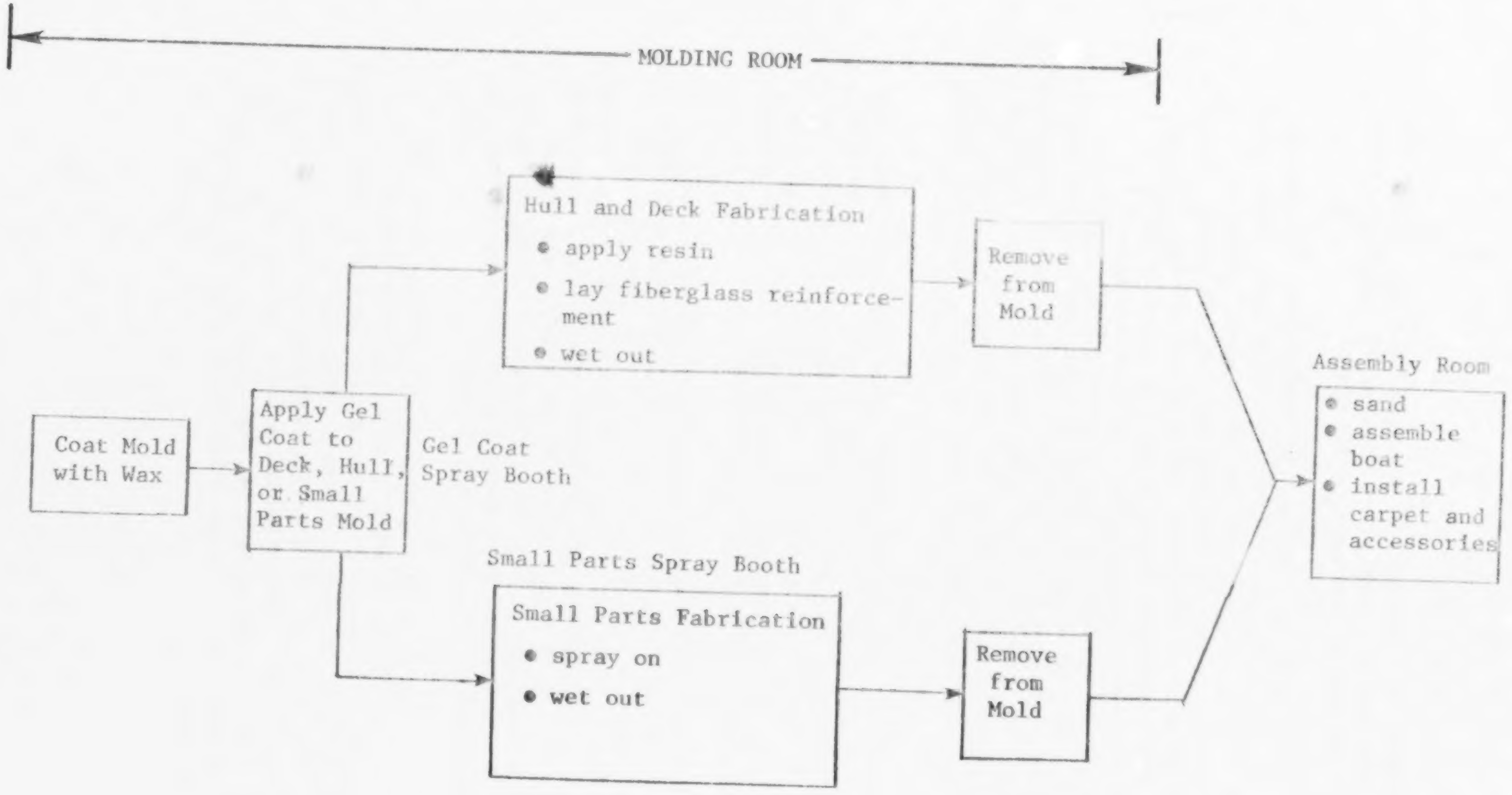
MOLDING ROOM
Coat Mold with Wax
Apply Gel Coat to Deck, Hull, or Small Parts Mold
Gel Coat Spray Booth
Hull and Deck Fabrication
• apply resin
• lay fiberglass reinforcement
• wet out
Remove from Mold
Small Parts Spray Booth
Small Parts Fabrication
• spray on
• wet out
Remove from Mold
Assembly Room
• sand
• assemble boat
• install carpet and accessories

Figure 2-1. Fiberglass boat production process.

through the reinforcement and remove any entrapped air (wet out). The resin is allowed to gel and the lamination process is repeated until the desired thickness of fiberglass laminate is obtained.

Three types of resin guns may be used in hand lay-up. These are catalyst injection, dual component, and hot pot. The most common type used in the industry are catalyst injection resin guns. Catalyst injection resin guns mix accelerated resin and the catalyst in the proper proportion inside the gun spray head and then spray the mixture through a single spray nozzle. With dual component resin guns, two streams of resin are sprayed simultaneously. One stream consists of resin premixed with accelerator and one stream consists of resin premixed with catalyst. The spray nozzles are aimed so the two spray streams mix outside the spray gun and then form a single spray stream. Hot pot resin guns have a pressure pot attached to the gun head. The laminator mixes the resin, accelerator, and catalyst in the pressure pot by hand. All of the resin must be sprayed once it has been mixed in the pot or it will gel inside the spray gun.

The spray-up method is an alternative to hand lay-up for hull and deck fabrication and is the most common method of small parts production. The spray-up method employs a chopper gun to simultaneously apply resin and chopped strands of glass reinforcement. Brushes and rollers are then used to spread the mixture and remove entrapped air. This process is repeated until the desired thickness is obtained.

The spray-up method is restricted to laminates using chopped glass strand as the reinforcement. Due to the type of reinforcement, laminates produced in spray-up have lower glass to resin ratios than the woven roving or cloth laminates produced in hand lay-up. Because the strength to weight ratio is proportional to the glass to resin ratio, laminates produced in spray-up also have lower strength to weight ratios than woven roving or cloth laminates. Laminates produced in hand lay-up with mat reinforcement are similar to those produced in spray-up because mat reinforcement is just chopped strand with a binder.

The advantage of using hand lay-up with woven roving or cloth laminate over spray-up is that a product with a higher strength to weight ratio is produced. However, the fabrication process takes longer when the hand lay-up method is used. A common practice in the industry is to combine these two methods. With this combination, parts of a boat that need to be strongest are fabricated using hand lay-up while parts that do not need as much strength, such as small parts, are fabricated using spray-up. This results in a lightweight boat that is produced in the minimum amount of time.

2.2.3 Cleanup

Cleanup of hands, tools, and spray guns is a very important part of the production of fiberglass boats. Tools such as brushes, rollers, and squeegies must be cleaned with a solvent after applying each batch of resin. Also, spray guns must be flushed with a solvent after each use and thoroughly cleaned daily. This cleaning prevents resin from curing on the tools and guns and making them unusable. In addition, periodic hand cleaning is also necessary for employee comfort. The cleaning solvent most commonly used is acetone and the following discussion is limited to acetone use.

Acetone is usually available for each employee in a 8 liter (2 gal) container for hand cleaning, a 19 liter (5 gal) container for tool cleaning, and a 11 to 19 liter (3 to 5 gal) container for spray gun cleaning. Also, most resin guns have a clean acetone feed line to flush the internal parts after each use. Acetone for hand cleaning must be relatively clean to avoid hand irritation, therefore, a method is generally adopted in which clean acetone is first used for hand cleaning. When the acetone becomes too contaminated for hand cleaning, it is transferred to the tool cleaning container until it is no longer effective for cleaning tools. Then the dirty acetone is transferred to a third container for soaking the resin gun between applications. Finally, when the acetone becomes too contaminated for any further use, it is transferred to a solvent recovery or disposal area. Each employee usually has his own set of hand and tool cleaning containers in the molding room and spray gun containers are available for each spray gun. The containers used may be open top or covered.

2.2.4 Sources of Emissions

There are generally two major sources of VOC emissions from fiberglass boat manufacturing facilities. These are acetone emissions from cleanup and styrene emissions from lamination.

2.2.4.1 Cleanup Emissions. The major source of emissions from fiberglass boat manufacturing facilities is the acetone emissions from cleanup of hands, tools and spray guns. Cleanup is usually done in the molding room. These emissions typically account for 80 percent of the total plant emissions if spent (contaminated) acetone is reclaimed.

As discussed in Section 2.2.3, tool and spray gun cleaning is usually required after applying each batch of resin. Also, employees must clean their hands periodically. When hands, tools, and spray guns are removed from the acetone, a good deal of liquid is carried out. This liquid readily vaporizes due to a large surface area per volume of acetone.

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Spray guns are normally flushed with acetone after each resin application. When spray guns are flushed, some of the atomized acetone vaporizes.

In addition to emissions resulting from cleanups, acetone also evaporates from any uncovered acetone containers in the molding room. Containers with lids are often used to reduce evaporation between cleanups.

2.2.4.2 Lamination Emissions. Styrene emissions occur during the lamination of the deck, hull and small parts. There are two sources of styrene emissions in each of these steps, the evaporation of the styrene from the resin or gel coat overspray and the vaporization of the styrene monomer from the applied resin or gel coat before polymerization occurs. Both of these sources of styrene emissions are discussed below.

As mentioned earlier, the resin can be applied by spraying or brushing while the gel coat is always sprayed. When spraying the resin or gel coat, approximately 90 percent is actually applied to the part and 10 percent is lost as overspray. If the resin is brushed on, then over 99 percent is actually applied to the piece with less than one percent of the resin being lost. The overspray is made up of small particles; therefore, there is more surface area for styrene evaporation. Because of this, all of the styrene evaporates before polymerization can occur.[7]

Styrene emissions also occur during the curing of the resin or gel coat. It is estimated that about eight percent of the styrene monomer in the applied resin or gel coat evaporates before polymerization is complete.

The Occupational Health and Safety Administration requires that the styrene or acetone concentration in the employee work area not exceed 100 ppm and 1,000 ppm, respectively. Because of this requirement all the styrene and acetone emitted in these operations are vented outside the building by the gel coat and small parts spray booth exhausts and in some facilities the molding room exhausts.

2.2.4.3 Other VOC Emission Sources. VOC emissions also occur in other areas in fiberglass boat building facilities. However each of these emissions are small compared to the emissions from cleanup and lamination.

There can be acetone emissions outside the building as a result of spent acetone disposal. This occurs because many manufacturers dispose of the spent acetone by placing it in open drums outside the building. The acetone is then allowed to evaporate and the remaining solids are disposed of. In addition, both styrene and acetone emissions can occur during the filling of the resin and acetone storage tanks, respectively. In some cases, facilities avoid these emissions by buying the materials in drums rather than having large storage tanks.

VOC emissions also occur in the assembly room during carpet application. As the carpet glue dries, the glue solvent evaporates into the room air.

2.2.5 Factors Influencing Acetone Emissions

The purpose of this section is to discuss the factors that affect acetone emissions in the molding room. Acetone emissions typically account for 50 to 80 percent of the total plant emissions. These emissions are due to carry out, atomization, and agitation of acetone during cleaning of hands, tools, and spray guns and evaporation of acetone from containers between cleanings. The major factors affecting emissions are the number of lamination employees, use of hand protection, use of covers on acetone containers, employee work habits, and resin gel time. All of these factors may vary from plant to plant.

The number of lamination employees directly affects total acetone emissions because each employee must clean his hands, tools, and spray gun (if used). Also, normal practice is for each employee to have his own set of acetone containers which increases the surface area available for acetone evaporation.

The use of hand protection affects the number of times the employees must clean their hands. The two types of hand protection available are gloves and barrier creams. Usually employees must clean their hands after every resin application (20 to 30 minutes). The use of gloves can reduce the number of cleanups to as low as four times daily.

Covered containers will reduce acetone emissions by reducing the evaporation from the acetone containers between cleanups.

Employee work habits can reduce emissions by reducing the amount of resin which must be removed from hands and arms. Some employees only get a minimal amount of resin on their hands and body while other employees may get considerably more on themselves. Employee work habits are mainly influenced by initial training and supervision.[8] Another factor which can affect the amount of resin which employees get on their hands and arms is the complexity of the mold. The more complex the mold the more difficult it is for employees to keep clean.

The gel time of the resin affects emissions because it determines the number of times that hands, tools, and spray guns must be cleaned in a given period of time. Shorter gel times mean more frequent resin applications and cleanings. Resin gel times can vary from 10 to 30 minutes. However, most resin gel times are about 15 minutes. If hand protection is used, resin gel time should not affect the frequency of hand cleanup as much as when no hand protection is used.

Other factors which affect acetone emissions are liquid level of acetone in the containers, air velocity across the containers, and room temperature. Increasing any of these factors will increase acetone evaporation. These factors are generally determined by the amount of acetone issued per employee, room air ventilation required for worker safety, and temperature required for resin curing. The amount of acetone issued can be reduced if gloves are used to reduce hand cleanup and covered containers are used to reduce acetone evaporation. Reducing the room air ventilation is not feasible to reduce evaporation because this would expose employees to higher concentrations of styrene vapors. The temperature required for proper resin curing is determined by the resin manufacturer and cannot be easily changed.

The resin application method (spray gun vs. brush application) is not one of the controlling factors affecting acetone emissions for the following reasons:

- All resin application methods require use of hand tools, such as rollers and squeegies, and hand contact with the resin.

- Brushes are generally used to smooth out resin applied with a resin gun. Four of five fiberglass boat manufacturers contacted who used resin guns also used brushes. Brushes used for resin application rather than for simple smoothing may require more thorough cleaning, however, the amount of acetone needed for thorough brush cleaning and resin gun cleaning is not appreciably different.

2.3 HYDRA-SPORTS PRODUCTION PROCESS AND EMISSIONS

The production process steps at Hydra-Sports Incorporated are identical to those shown in Figure 2-1. Hydra-Sports has two gel coat booths and one small parts booth contained in the molding room. The gel coat used consists of 25 percent styrene monomer and 75 percent pigmented solids. Following the gel coat, Hydra-Sports uses the hand lay-up method described in Section 2.2.2 for hull and deck production. Batches of catalyzed resin (1 to 2 percent catalyst) are prepared in 4 liter (1 gal) buckets and then applied with brushes. A typical gel time of the batch is 15 minutes. The spray-up method described in Section 2.2.2 is used for production of small parts. The resin used is a general purpose polyester resin composed of approximately 42 percent styrene and 58 percent resin solids.

Hydra-Sports uses acetone as a solvent for cleaning hands, tools, brushes, chopper guns, and gel coat spray guns. On the average, Hydra-Sports uses 106 liters (28 gal) of gel coat, 790 Mg (1,740 lbs) of resin for hull and deck production, 14 kg (30 lbs) of resin for small parts production, and 405 liters (107 gal) of acetone each day.

The VOC emissions at Hydra-Sports are shown in Table 2-1, by source and type. These emissions result from the evaporation of styrene, acetone, and carpet glue solvent. As shown in Table 2-1, the major sources of VOC emissions are acetone evaporation during cleanup and styrene evaporation during deck and hull fabrication. These two sources make up 89 percent of the total plant emissions.

Hydra-Sport's emissions have decreased over the last five years due to a drop in production. The historical total emissions from 1977-1980 are shown in Table 2-2. Hydra-Sports has emitted more than 90 Mg (100 tons) per year of VOC in the past and still has the potential to emit more than 90 Mg (100 tons) per year of VOC.

The VOC emissions resulting from the cleanup and lamination operations are vented to the atmosphere by the small parts spray booth and the two gel coat spray booth exhausts. The air flow rate for each of these three exhaust systems or emission points is rated at 280 m^3/min (10,000 cfm). The two gel coat spray booth exhausts operate eight hours daily and the small parts spray booth exhaust operates four hours daily. The exit concentrations at these emission points have not been measured. However, the calculated average based on yearly emissions is 186 ppm acetone and 27 ppm styrene. All other emissions are fugitive emissions and cannot be identified with any one emissions point.

Hydra-Sports produces 65,900 liters (17,400 gal) of spent acetone per year which contains 15 percent resin solids by volume. This represents 44.3 Mg/yr (48.9 tons/year) of acetone. Hydra-Sports dilutes this spent acetone 50/50 with water and disposes of it off site. Therefore, the evaporation of this acetone does not contribute to Hydra-Sport's emissions inventory. Instead this acetone will probably evaporate at the disposal site.

TABLE 2-1. HYDRA-SPORTS VOC EMISSIONS, Mg/yr (tons/yr)[a,b,c]

Source	Acetone Emissions	Styrene Emissions		Glue Solvent Emissions	Total
		Application	Curing		
Cleanup	35.6 (39.6)	--	--	--	35.6 (39.6)
Lamination					
Deck and Hull Fabrication	--	0.8 (0.9)	5.8 (6.5)	--	6.7 (7.4)
- Small Parts Fabrication	--	0.18 (0.2)	1.0 (1.1)	--	1.2 (1.3)
- Gel Coat Application	--	0.7 (0.8)	0.5 (0.6)	--	1.3 (1.4)
Assembly Room	--	--	--	2.7 (3)	2.7 (3)
Storage Losses	NR	--	--	NR	0.04 (0.05)
TOTAL	35.6 (39.6)	1.7 (1.9)	7.4 (8.2)	2.7 (3)	47.5 (52.8)

[a] NR = Not Reported.

[b] Since Hydra-Sports operates 2,000 hrs/yr, the emission rate in tons per year equals the emission rate in pounds per hour.

[c] Hydra-Sports also disposes of 44.3 Mg/yr (48.9 tons/yr) of waste acetone offsite. While this acetone does not directly contribute to emissions at Hydra-Sports, it probably evaporates at the disposal site.

TABLE 2-2. VOC EMISSIONS - HYDRA-SPORTS (1977-1980)[a]

Source	1977		1978-79		1980	
	Mg/yr	(tons/yr)	Mg/yr	(tons/yr)	Mg/yr	(tons/yr)
Cleanup						
acetone	86	(95)	43	(48)	36	(40)
Lamination - styrene						
Deck and Hull Fabrication	1.8	(2)	1.8	(2)	6	(7)
Small Parts Fabrication	2.7	(3)[b]	0.9	(1)	1.3	(1.4)
Gel Coat Application			0.18	(0.2)	1.2	(1.3)
Carpet Glue Solvent	6	(7)	7	(8)	2.7	(3)
TOTAL	96.5	(107)	52.9	(59.2)	47.2	(52.7)

[a] Emissions from storage losses are small and are not shown.

[b] This styrene emissions value is the sum of the small parts fabrication and the gel coat application.

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3.0 EMISSION CONTROL TECHNIQUES

This chapter discusses three emission control techniques which have the potential to reduce VOC emissions from fiberglass boat building. Sections 3.1 and 3.2 discuss process changes to control acetone and styrene emissions, respectively. Section 3.3 describes add-on controls for the exhaust air streams. The applicability of these controls at Hydra-Sports is discussed in Section 3.4.

3.1 CONTROLS SPECIFICALLY FOR ACETONE EMISSIONS

Two types of controls may be used to reduce acetone emissions substantially. Work practice controls can reduce acetone emissions due to cleanup and spent acetone reclamation can reduce or eliminate emissions due to spent acetone disposal.

3.1.1 Description of Work Practice Controls

Several work practices are used in the fiberglass boat building industry to reduce acetone emissions. These include hand protection, covered acetone containers, and limited issue of acetone. As discussed in Section 2.2.3, the use of hand protection and closed containers reduces acetone emissions from cleanup. Also limiting issue of acetone encourages less cleanups and conservation of acetone by employees.

Data were obtained from nine fiberglass boat manufacturers on acetone use. These data are shown in Table 3-1 and are presented graphically in Figure 3-1. These facilities varied in their method of resin application. The method of resin application is not shown because it is not a controlling factor for acetone emissions. Also shown in Figure 3-1 are the work practice controls in place at each facility. The acetone emissions at each facility are shown on a per employee basis to show the influence of work practice controls. The degree of control ranges from a worst case of no controls up to the best control which is use of gloves by lamination employees, combined with covers for all acetone containers. Figure 3-1 shows a general trend of decreasing acetone emissions with the application of work practice controls. The variations between facilities employing the same control are believed to be due to differences in the amount of resin each worker has to remove from his hands and arms which depends on his ability to laminate neatly. The facilities shown produce boats of a type and size similar to those produced at Hydra-Sports. Therefore, the molds at all these facilities should be of similar size and complexity.

TABLE 3-1. ACETONE ISSUED AND RECOVERED FOR 9 BOAT BUILDERS

Plant	Acetone issued per day (gal/employee)	Amount of Waste (acetone & solids) Recovered per day (gal/employee)	Solids Content of Recovered Waste[b] Vol. (%)	Amount of Acetone Recovered per day (gal/employee)	Acetone Emissions per day (gal/employee)	Acetone Emissions per day (lb/employee)
Hydra-Sports	6.0	3.9	15	3.3	2.7	18
B	6.7	4.4[a]	15	3.7	3.0	20
C	1.4	0.7[a]	30	0.49	1.2	7.9
D	3.2	1.6[a]	30	1.12	2.1	14
E	1.7	0.8[a]	30	0.56	1.3	8.6
F	0.5	0.25	30	0.18	0.3	2.0
G	2.8	1.0	30	0.7	2.1	14
H	2.0	1.0[a]	30	0.7	1.3	8.6
I	0.15	.06	30	0.04	0.1	0.7

[a] Amount recovered was unknown. Therefore, the amount recovered was estimated from data for facilities with similar acetone issue rates. For Plant B this value was 65 percent of the acetone issued. For the other plants, this value was 50 percent of the acetone issued.

[b] Only Hydra-Sports provided data on the solids content of the recovered waste acetone. For Plant B the solids content was assumed to be the same as Hydra-Sports because both plants issue a similar amount of acetone. For all other plants the solids content was estimated to be 30 percent based on information provided by a vendor.[1] The 30 percent value was used to give a more conservative estimate of the acetone emission reduction due to work practice controls.

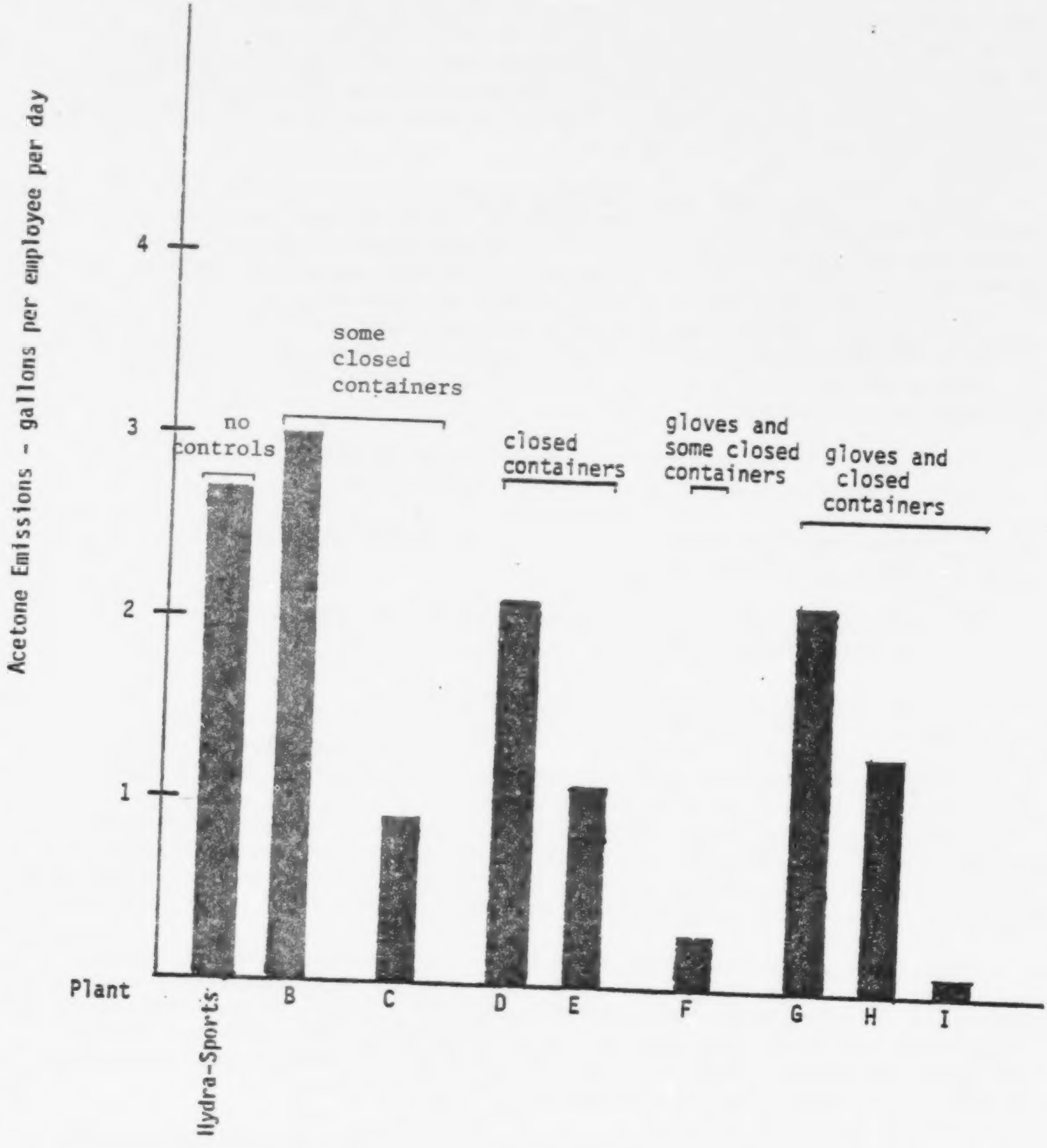

Figure 3-1. Molding room acetone emissions as a function of work practice controls.

If the emissions from Hydra-Sports, which has the lowest emissions for the no controls case, are compared with the emissions from Plant G, which has the highest emissions for the best controlled case, then a conservative estimate of the acetone emissions reduction which could be achieved using the best work practice controls can be calculated. This comparison shows that at least a 22 percent reduction in acetone emissions can occur.

Table 3-1 also shows that applying work practice controls can reduce the amount of acetone which must be issued to each employee and reduce the amount that must be sent to solvent recovery or disposal. Based on Table 3-1, the average amount of acetone issued per employee is 3.0 gallons (excluding Plant I which showed an unusually low amount of acetone issued). Therefore, applying work practice controls would allow the best plant with no controls (Hydra-Sports) to limit acetone issue to 50 percent of the present level. This reduction limit on acetone issue provides three benefits:

- Limiting the amount of acetone issued reinforces the other work practices by encouraging conservation.
- Reducing the amount issued will provide a material cost savings because less must be purchased.
- Reducing the amount of spent acetone will result in less acetone requiring recycle and disposal.

3.1.2 Description of Spent Acetone Reclamation

Some fiberglass boat manufacturing facilities dispose of spent acetone by allowing it to evaporate. This practice can account for as much as 50 percent of the total plant acetone emissions. Others, like Hydra-Sports, dispose of it off-site which can potentially cause VOC emissions at the dump site. These acetone emissions can be reduced or eliminated by recycling the spent acetone. Two options are available, on-site recovery or sending spent acetone to a commercial solvent reclaiming facility. Both offer economic and environmental benefits.

On-site acetone recycling can reduce spent acetone disposal emissions by 90 percent.[1] Recycling units are available in sizes compatible with the needs of fiberglass boat manufacturing operations. These units come completely assembled, but require cooling water and electricity. Also, insurance companies often require that the unit be located away from the facility thus requiring a separate shelter for the unit.

Alternatively, there are commercial facilities that reclaim acetone. Emissions due to spent acetone disposal can be eliminated by sending spent acetone out for reclamation. An additional benefit of this method is that the fiberglass boat manufacturer also gets rid of solid waste in the acetone.

3.2 PROCESS CHANGES FOR CONTROL OF STYRENE

Styrene emissions can be reduced by converting to polyester resins that are designed to reduce styrene losses. These conversions include resins containing a suppressant and resins with a low styrene content.

3.2.1 Styrene Suppressed Resins

Styrene suppressed resins decrease emissions by entrapping some of the styrene monomer that would otherwise vaporize during exothermal curing of the resin. Suppressed resins are capable of reducing styrene emissions from the curing process by as much as 75 percent. This will reduce total styrene emissions by about 50 percent.[2] According to vendors, these resins are priced about the same as conventional resins and can be directly substituted. Three of twelve fiberglass boat manufacturers contacted are presently using a suppressed resin with satisfactory performance. However, some boat manufacturers have not been able to achieve satisfactory performance from suppressed resins and have experienced problems with delamination.[3] Due to confidential formulations, different brands of suppressed resin vary in performance and method of suppression. Selection of a brand of suppressed resin would require production testing in order to determine its suitability and its effect on product quality.

3.2.2 Low Styrene Resins

A conversion to low styrene resin is another method of reducing styrene emissions. The conversion to these resins reduces styrene emissions because their styrene monomer content is as low as 35 percent compared to 42 to 50 percent in conventional resins.[2] The cost of low styrene resins is approximately the same as conventional resins and according to vendors, they can be directly substituted for conventional resins. Emission reductions during curing due to the conversion to low styrene resins are about 17 to 30 percent which is equivalent to an overall reduction in total styrene emissions of 11 to 20 percent. Four out of twelve fiberglass boat manufacturers contacted report they are presently using a low styrene resin.

3.3 ADD-ON CONTROLS

Add-on controls are applicable to emissions from spray booth exhausts and room air vents. Two types of add-on controls were investigated, chemical scrubbing and incineration.

3.3.1 Description of Gas/Liquid Chemical Scrubber

One vendor suggested investigating a gas/liquid chemical scrubber that could control acetone and styrene emissions. In this system, chemical scrubbing removes organic vapors from a gas by absorbing them into a liquid. The absorbed organic materials are then destroyed by chemical reaction with one or more components of the liquid. This scrubber uses sodium hydroxide or a mixture of sodium hydroxide and sodium hypochlorite as the scrubbing liquid. The vendor who markets this scrubber estimated a VOC removal of 90 percent or more.[4] However, there are two problems with this system. These are:

- This scrubber has not been demonstrated to control styrene and acetone vapors.

- This scrubber would produce a liquid waste stream which would have to be treated.

For this system to be used, preliminary testing would have to be done to determine its applicability for controlling styrene and acetone emissions from fiberglass boat manufacturers. In addition, the impact of the liquid waste stream on solid waste or water pollution would have to be investigated.

3.3.2 Description of Incineration

Two types of incinerators are available, thermal and catalytic. Thermal incineration involves the oxidation of organic vapors to carbon dioxide and water. The solvent laden air is exposed to a high temperature of 540° to 820°C (1000 to 1500°F) and in some cases a direct flame for a period of 0.3 to 0.6 seconds. Catalytic incinerators use a catalyst bed to oxidize the organic vapors and operate at reduced temperatures of 400° to 540°C (750° to 1000°F). Important incineration design factors are residence time, gas stream flow rate, operating temperature, and waste gas heat content.

When collected, most waste gases have low heat contents. This is due in part to insurance regluations which limit the maximum concentration of organics to 25 percent of the lower explosive limit (LEL) when no LEL meter is used. If an LEL meter is present to constantly monitor the gas stream then the organic concentration can be as high as 40 percent of LEL. In either case supplemental fuel is needed to raise the off gases to the required operating temperature.

Heat recovery equipment may also be used with incinerators to reduce the amount of supplemental fuel required. It is generally divided into primary and secondary recovery. Primary heat recovery uses heat exchangers to recover heat from the incinerator exhaust gases to heat the incoming air. Secondary heat recovery recovers heat from the exhaust gases for use in plant processes such as ovens, dryers, etc.

The destruction efficiency of both thermal and catalytic incinerators depends on the residence time and temperature. In general these devices can be designed to achieve between 90 and 99+ percent destruction of VOC.

Incinerators have not been demonstrated as VOC control devices in the fiberglass boat manufacturing industry. The main problem results from the low VOC concentrations in the exhausts and high exhaust air flows. Calculated VOC concentrations in the exhaust streams average 27 ppm for styrene and 186 ppm for acetone. These conditions would result in the exhaust stream having a low heat content thus resulting in high supplemental fuel requirements.

3.4 CONCLUSIONS

The technical and economic feasiblity of each control technique was assessed for application at Hydra-Sports. The potential controls selected for further consideration as a RACT option are work practice controls, low styrene resins, and commercial acetone recycling. Work practice controls include use of hand protection, covered acetone containers, and limited acetone issue. Low styrene resins were selected over styrene suppressed resins because of delamination problems with the styrene suppressed resins. Commercial acetone recycling was selected over on-site recycling because it requires no initial investment to implement, and has the added benefit of allowing Hydra-Sports to dispose of their solid waste from resin cleanup. As discussed in Sections 3.1 and 3.2, applying these controls could reduce acetone emissions in the molding room by 22 percent, styrene emissions by 11 to 20 percent, and eliminate acetone emissions at the acetone dumpsite. The environmental impacts and costs of these controls are presented in Chapters 4 and 5, respectively.

For chemical scrubbing and incineration, preliminary estimates showed both controls to be too expensive so they were dropped from further consideration. The cost of chemical scrubbing is approximately $1,700/ton VOC removed and the cost of catalytic or thermal incineration ranges from $4500 to $7000/ton VOC removed.[5]

3.5 REFERENCES

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5. Memo from Barnett, K., Radian Corporation, to file. November 10, 1981. 4 pp. Cost estimates for incineration and chemical scrubbing for control of VOC emissions from fiberglass boat building.

4.0 ENVIRONMENTAL IMPACTS

This chapter discusses the environmental impacts of work practice controls at Hydra-Sports, Inc. Sections 4.1 through 4.4 discuss the air pollution, water pollution, solid waste pollution and energy impacts that result from the application of these controls, respectively.

4.1 AIR POLLUTION

Table 4-1 presents the emission rate of acetone, styrene, and total plant VOC emissions before and after the controls are applied. The VOC emissions reduction for work practice controls at Hydra-Sports is estimated to be 7.9 Mg/yr (8.8 tons/year) or 17 percent of total plant emissions. The controls include covered acetone containers, hand protection, and limited issue of acetone. Low system resins will reduce styrene emissions by 1.2 Mg/yr (1.3 tons/year). As shown in Table 4-1, these controls result in the reduction of molding room emissions only. They do not generate any secondary air pollutants. Table 4-1 also shows that recycling spent acetone will eliminate acetone emissions at the dumpsite where the spent acetone is presently disposed of. This will result in an emissions reduction of 44.3 Mg/yr (48.9 tons/yr).

4.2 WATER POLLUTION

These controls do not result in discharge of any water.

4.3 SOLID WASTE POLLUTION

These controls do not result in any increase in solid waste disposal with the exception of the need to dispose of 18 pairs of soiled rubber gloves every day.

4.4 ENERGY IMPACTS

These controls do not result in increased energy consumption for Hydra-Sports.

TABLE 4-1. EMISSIONS BEFORE AND AFTER WORK PRACTICE CONTROLS, Mg/yr (tons per year)[a,b]

	Uncontrolled		Controlled	
Acetone Emissions	35.6	(39.6)	27.7	(30.8)
Styrene Emissions	9.1	(10.1)	7.9	(8.8)
Total Plant VOC Emissions	47.5	(52.8)	38.4	(42.7)
Emissions due to acetone disposal	44.3	(48.9)	0	

[a] Since Hydra-Sports operates 2,000 hrs/yr, the emissions in tons per year equals the emissions in pounds/hour.

[b] VOC emissions from glue solvents are the same with and without controls and are not shown.

5.0 EMISSION CONTROL COST ANALYSIS

This chapter presents and discusses emission control costs including capital costs, annualized costs, and cost effectiveness for work practice controls. Sections 5.1 and 5.2 discuss the bases used for the capital and annualized costs, respectively. Section 5.3 presents the control costs and Section 5.4 presents the cost effectiveness.

5.1 BASIS FOR CAPITAL COSTS

Adoption of work practice controls at Hydra-Sports would require purchase of covered containers for acetone. Table 5-1 presents the number and sizes of the containers required per employee. The costs of these items were obtained from safety equipment vendors.[1,2] The total capital cost was based on vendor prices of equipment plus tax. Hydra-Sports has 18 lamination employees who would each need three covered containers. There would be no other installed capital costs for work practice controls due to the simplicity and nature of these controls. There are no capital costs for converting to low styrene resins or commercial acetone recycling.

5.2 BASIS FOR ANNUALIZED COSTS

Table 5-2 shows the bases used to calculate the annualized costs for acetone work practice controls. Two cases were analyzed; one based on an issue of 6 gallons of acetone per day per lamination employee as currently practiced by Hydra-Sports, and one on 3 gallons, the current industry average. Based on the data presented in Table 3-1, acetone issue could be reduced to as low as 0.15 gallons per day.

Periodic purchase of gloves is necessary for work practice controls. The cost of gloves suitable for use in production of fiberglass boats was obtained from safety equipment vendors.[3] The cost of gloves was estimated based on 250 days per year of operation and that each employee requires one pair of gloves per day.

Also shown is the bases used to calculate the acetone cost credit per gallon due to commercial reclaiming of spent acetone. There are no annualized costs for conversion to low styrene resins.

The capital recovery factor was based on a 12 percent interest rate and a 5 year equipment life. Hydra-Sports presently issues 6 gallons per day of acetone per employee. As discussed in Section 3.1.1 applying work practice controls would reduce evaporative emissions by 0.6 gallons per employee per day. This reduction in evaporative losses can be considered in three ways. In the first and second cases it could be assumed that the acetone from the 6 gallon/day issue that is left over at the end of the day can be reused or disposed of. If the spent acetone is simply disposed of no credit could be

TABLE 5-1. EQUIPMENT REQUIRED FOR WORK PRACTICE CONTROLS

Equipment	Cost Source
One gallon covered container (hand cleaning)	Safety equipment vendors
Four gallon self closing container (tool cleaning)	
Three gallon safety can (for issue)	

TABLE 5-2. ANNUAL OPERATING COSTS BASES

Days of operation per year	250
Gloves for hand protection	1 pair per employee per day at $8.50 per dozen (for 18 employees)
Acetone Cost	$1.91 per gallon
Acetone Cost Credit	
If acetone issue of 6 gallons per employee per day is maintained	None
If acetone issue is reduced to 3 gallons per employee per day	3 gallons per employee per day
Capital Recovery Factor	27.7% (Based on 12 percent interest rate and 5 year equipment life)
Cost Credit for Recycling spent acetone	$0.23 per gallon of acetone recycled.
Amount of acetone for disposal	
6 gallons per day issue	17,400 gallons/year (58 tons/year)
3 gallons per day issue	4,000 gallons/year (13.5 tons/year)

taken. However, if it were saved and used the next day a credit could be taken. The third way that the reduction in evaporative losses could be considered is by reducing the issue of acetone from 6 gallons to 5.4 gallons per employee per day. This issue reduction can occur because the work practice controls prevent 0.6 gallons of acetone from evaporating. The employees of Hydra-Sports would still have the same net amount of acetone available for clean up. Two of the cases described above have the same cost credit since both result in a reduced amount of acetone purchased.

For the 3 gallon/day issue case no credit for reduced evaporation is taken because this level of issue assumes that acetone evaporative losses have been minimized. However, a 50 percent credit is taken for the reduced amount of acetone that has to be purchased. In addition the amount of spent acetone requiring disposal would be substantially reduced.

5.3 EMISSION CONTROL COSTS

The estimated capital cost and annualized cost of work practice controls are presented in Table 5-3. Work practice controls are estimated to result in a savings of $22,000 per year if issue of acetone is limited to 3 gallons per day per employee. If Hydra-Sports is unable to limit acetone issue to 3 gallons and simply reduces evaporative losses of acetone, savings will be $1,240 per year. If no credit is taken for the reduction of acetone emissions under the 6 gallon case the work practice controls would cost $3,800 per year.

Table 5-4 shows the estimated annual cost savings achieved by commercial acetone recycling. Commercial recyclers will pay up to $0.23 per gallon of spent acetone recycle. Normally this payment is made in the form of reducing the cost of the new acetone purchased. Use of commercial recycling for spent acetone disposal will result in an annual cost savings of $930 to $4,000 depending upon how much spent acetone is issued to each laminator and how much is subsequently recycled. Acetone recycling will also result in a VOC emissions reduction of between 11 to 47.5 Mg/yr (12 to 52 tons per year) assuming 90 percent of the acetone sent to the recycler is recovered.

5.4 COST EFFECTIVENESS

Work practice controls at Hydra-Sports are estimated to result in a VOC emissions reduction of 7.9 Mg/yr (8.8 tons per year). Table 5-3 shows that this results in a savings of $2,500/ton of emissions reduction for the 3 gallon/day issue case and a savings of $140/ton of emissions reduction for the 6 gallon issue case where a credit for reduced evaporation is taken. If Hydra-Sports simply reduces evaporative losses, maintains a 6 gallon/day issue and disposes of the 0.6 gallons acetone saved by the work practice controls, cost effectiveness will be $430/ton of emissions reduction. Table 5-4 shows that commercial acetone recycling results in a savings of $77/ton of acetone recovered.

TABLE 5-3. COST OF WORK PRACTICE CONTROLS

	3 gallon/day issue	6 gallon/day issue
Capital costs	$2,200	$2,200
Capital charges for covered containers	600	600
Operating expenses for purchase of gloves	3,190	3,190
Credit for reduced acetone evaporation	a	5,040 (0)[b]
Savings from reduced acetone purchased	25,800	c
Total annualized cost[d]	-22,000	-1,240 (3,800)[b]
Amount of acetone evaporation reduced tons/year	8.8	8.8
Cost effectiveness of work practice controls	$-2,500/ton of of emissions reduction	$-140 (430)[b]/ton of emissions reduction

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[a] No credit for reduced evaporation is taken for the 3 gallon case because this level of issue assumes that acetone evaporation losses have been minimized.

[b] Without credit for evaporative losses.

[c] There would be no savings in acetone because the plant currently issues 6 gallons/day. However, because evaporation has been reduced by 0.6 gallons/person/day, Hydro-Sports would reduce the acetone issued to 5.4 gallons/day.

[d] Negative annualized cost means annual savings.

TABLE 5-4. COSTS OF RECYCLING SPENT ACETONE

	3 gallon/day issue	6 gallon/day issue
Gallons of spent acetone generated per year	4,000	17,400
Annual Savings	$ 930	$ 4,000
Acetone recovered @ 90% recovery	12 tons/year	52 tons/year
Cost effectiveness of recycling	$-77/ton recovered	$-77/ton recovered

5.5 REFERENCES

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2. CAH Industries, Inc. Flame Tamer.® Fire Prevention & Safety Products. Elk Grove Village, IL. Price list No. 133. July 1, 1981. 8 pp.

3. Telecon. Howle, R., Radian Corporation with Forstrum, D., Conney Safety Products Co. August 13, 1981. Gloves for hand protection.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The purpose of this study was to determine if several site-specific volatile organic compound (VOC) emission sources in Louisville, KY and Nashville, TN were applying reasonably available control technology (RACT) to control emissions. The facilities examined included two aluminum rolling mill lubricant sources, a furniture coating plant, and a fiberglass boat manufacturing plant. None of the examined sources currently have RACT in place. For aluminum rolling mill plants the best RACT option appears to be the substitution of a linear paraffin rolling oil for the kerosene-based lubricants currently used. The best RACT option for furniture coating was determined to be the use of electrostatic spraying equipment. For the fiberglass boat manufacturing source, work practice controls, low styrene resins, and commercial acetone recycling were determined to be the best potential RACT options for VOC control.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Kentucky	Furniture Coating	Louisville, Kentucky	
Tennessee	Fiberglass Reinforced	Nashville, Tennessee	
Cost Effectiveness	Plastic	Surface Coating Industry	
Hydrocarbons	Fiberglass Boat Building	Boat Manufacturing	
Air Pollution Control		Unclassified	
Aluminum Rolling Mills		Unclassified	
Cold Rolling			
Rolling Mill Lubricant Control			

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